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STUDY OF A TRACKING AND DATA ACQUISITION SYSTEM (TDAS) IN THE 1990'S

SECOND QUARTERLY TECHNICAL PROGRESS REPORT

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Prepared for:

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Submitted under:

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16. Abstract

This report covers the second quarterly reporting period for the Tracking and Data Acquisition Systems Study (TDAS). This is a two year contract effort by Stanford Telecommunications, Inc., with subcontractor support on certain tasks from Fairchild Space and Electronics Co. and Satellite Communications Co., for Goddard Space Flight Center. This study is a pre-Phase A concept definition study. The proposed TDAS will be the follow-on to the Tracking and Data Relay Satellite System (TDRSS) which is currently in development.

This technical progress report covers technical activities and accomplishments for the quarterly reporting period ending October 31, and work plans for the following quarter. The primary thrust of the report is detailed under the "Spacecraft Data System Architecture" and "Communication Mission Model" tasks. However, all active tasks are documented. Two other tasks with significant activity reported here are the "Frequency Plan and Radio Interference Model Development," and "Viterbi Decoder/Simulator Study." The "Communication Mission Model" Task is essentially complete as of the end of this reporting period. The others are scheduled for additional work in the next quarterly period.

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PREFACE

OBJECTIVE

The objective of this report is to document the scientific and engineering results obtained as a result of work during the first quarterly reporting period on Contract NAS5-26546, "Tracking and Data Acquisition (TDAS) Study". The report covers the period from July 31 to October 31, 1981. It includes a bibliography of pertinent documents from NASA and industry sources.

SCOPE OF WORK

This contract represents a two-year pre-Phase A concept definition study for the proposed Tracking and Data Acquisition Satellite system (TDAS), which will be on the follow-on to Tracking and Data Relay Satellite System (TDRSS) which is currently in development. The TDRSS is contracted for through about 1994. This TDAS study therefore covers a ten-year planning period starting in the early 1990's.

Much of the TDAS requirement will be to support low earth orbit (LEO) missions in terms of communications, navigation, and TT&C. Additional requirements could stem from user mission activities in higher (e.g., synchronous) orbits, and in support of inter-orbital transfers of materials and men for maintenance and repair in space, or for retrieval of platforms and experiments. The scope of work also covers examination of the possibility of using TDAS resources in support of deep space experiments.

The main thrust of the contract involves defintion of the TDAS system architecture, followed by significant cost performance tradeoff activities involving both TDAS and User Space and ground segment cost and performance, to assure the resulting concept alternatives are both technically and operationally viable.

In the initial development of mission profiles, military requirements for TDAS support are excluded. However, these will be added as the work progresses. Shuttle flights carrying military missions are assumed to require TDAS support to the shuttle vehicle in all cases.

SUMMARY OF TASK ACTIVITIES

In active tasks during this report period, various aspects of the TDAS timeframe were investigated. These included:

- Spacecraft Data System Architecture - Preliminary steps were undertaken for developing the system architectures. This included review of user requirements data from Task 1 and the results of technology forecasts on sensor data handling, navigation and communications systems. Efforts also began on determining the constraining missions based on the scenarios of mission models developed in Task 3.

- Communication Mission Model - Using baseline plans data from Task 1, four scenarios of mission models are being developed for use in comparison of alternative TDAS architectures. These are based both on differing budget assumptions and possible operational constraints (e.g., experiment carriers).

- User Ground Data System Architecture - General requirements for the user ground system are being developed using data from the Communication Mission Model, together with some follow-up interviews of NASA planners relative to user ground aspects of some programs such as ST, SASP, and PUP. The work will lead to development of ground segment options leased on a preliminary technology assessment and estimate of operational constraints, together with ground system cost estimating data and cost/performance assessment simulation program elements.

- Frequency Plan and Radio Interference Model Development - TDAS frequency utilization plans are being developed for the configurations studied, and both classified and unclassified existing data bases will be drawn upon to develop RFI models for each communications band utilized. The work will lead to development of system survivability models for each system or signal structure, and system requirements for robust operation in each signal environment.

- Frequency Management - Through active liaison with NASA frequency managers and various coordination, assignment, use management and planning groups, TDAS frequency utilization plans and assignments will be developed relative to the 1984 WARC. Frequency constraints and proposed solutions will be developed relative to TDAS for use in frequency planning meetings and study reports.

- Threat Model Development/Security Analysis - The work on the Satellite Control Satellite (SCS) study by STI/Ford Aerospace will be reviewed as a basis for threat modeling and analysis for TDAS. SCS developed a system for relay of military satellite communications which is similar in concept to TDAS. The SCS work will be extended to account for the frequency plans, configurations, signal formats, etc. established for TDAS in other tasks. Using updated threat assessments, a threat model for TDAS will then be developed. This model will make possible the determination of the security of the TDAS. First an applicable definition of security will be formulated, and this will be used to determine acceptable ranges of values for system parameters such as data rate, EIRP, G/T, etc.

- Spacecraft Cost Model - The SAMSO cost model (5th ED.) is being combined with recent NASA program cost experience to reformulate certain cost estimating relationships. This will lead to an upgraded spacecraft program cost model for the TDAS program.

- Viterbi Decoder/Simulator Study - Viterbi Decoder performance in the presence of pulsed RFI with varying intensity, repetition rate and duty cycle is being studied using both a hardware simulator (from Linkabit) and a software simulator (from STI). Performance results will be expressed in terms of synchronization and tracking capabilities.

- Deep Space Support - Initial efforts to gather background data necessary for defining scenarios of experiments pertaining to deep space activity in the 1990s were made. A temporary hold was placed on further activity pending JPL efforts to update their planning models.

CONCLUSIONS

At the end of each task, conclusions will be developed for inclusions in the following quarterly technical progress report. There are no conclusions for this report since all active tasks remained active through the end of the reporting period, except for Task 1, which was covered in the First Quarterly Report. A separate draft final report for Task 1 covers its conclusions in detail.

SUMMARY OF RECOMMENDATIONS

At the end of each task, recommendations will be developed for inclusion in the following quarterly technical progress report. There are no recommendations for this report since all active tasks remained active through the end of the reporting period, except for Task 1, which was covered in the First Quarterly Report. A separate Task 1 draft final report contains all results for that task assignment.

2nd QUARTERLY REPORT

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SECTION 1

INTRODUCTION

This section defines the scope and purpose of the report, and provides a brief summary of work in the reporting period. It also defines the contents of the report.

1.1 SCOPE OF REPORT

This report provides the second Quarterly Progress Report in accordance with contract Article XX (Type II Technical Progress Report) for Contract NAS5-26545, titled "Tracking and Data Acquisition (TDAS) Study". This reporting period covers the activities from 31 July thrugh 31 October 1981.

This report covers all Task/Assignments issued under the contract during the reporting period, including references to tasks not scheduled to start until later. Task initiation prior to 31 October was scheduled for the following tasks:

- T/A #1 - User Community Characteristics
- T/A #2 - Spacecraft and Data System Architectures
- T/A #3 - Communications Mission Model
- T/A #4 - User Ground Data System Architecture
- T/A #10 - Frequency Plan and Radio Interference Model Development
- T/A #10A - Frequency Management
- T/A #11 - Threat Model Development/Security Assessment
- T/A #12 - Upgrading the SAMSO Cost Model
- T/A #13 - Viterbi Decoder/Simulation Study
- T/A #13A - Ku-Band Performance with Presence of RFI
- T/A #14 - Deep Space Support

The remainder of the tasks will be initiated in accordance with the schedule as shown in Figure 1-1.

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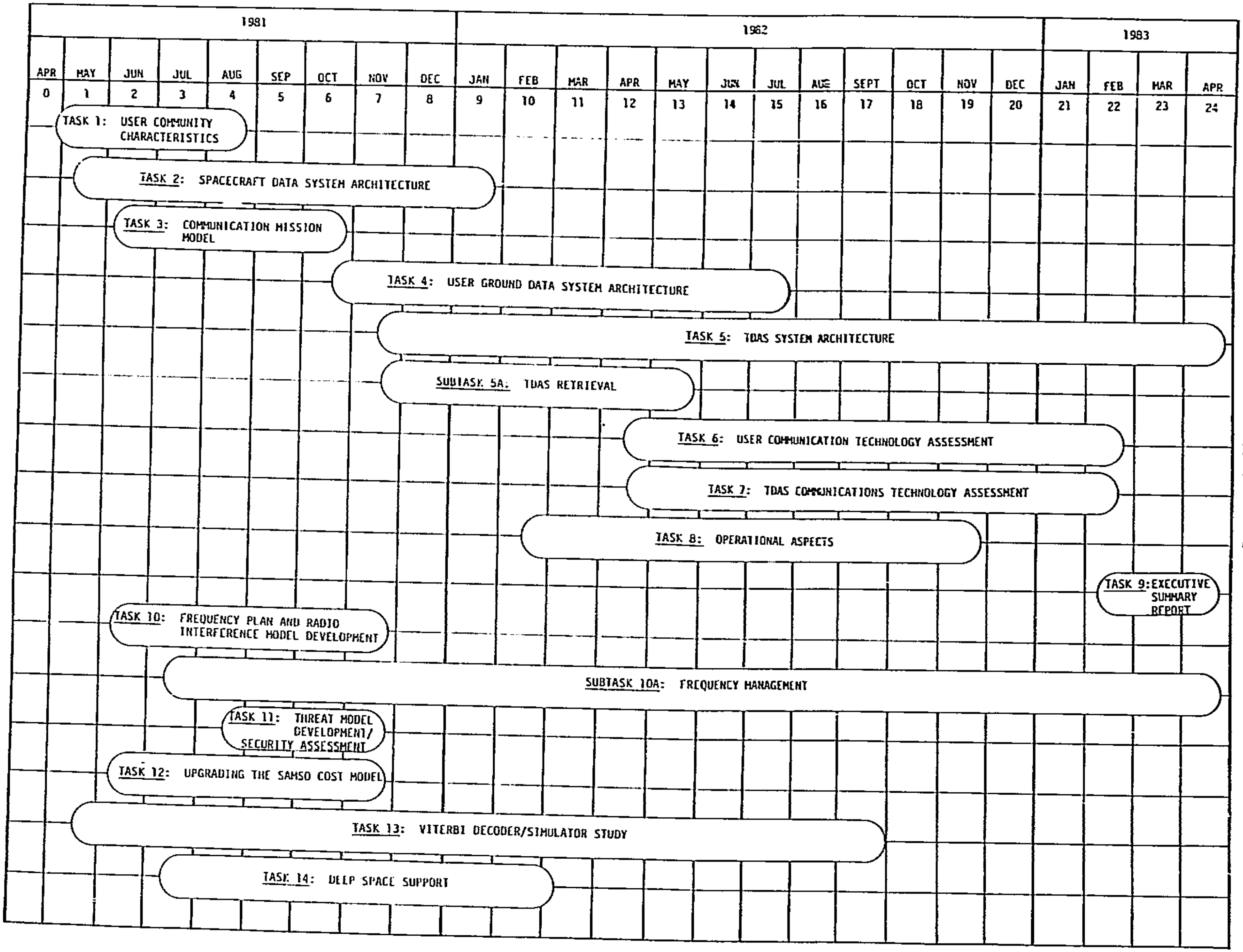

FIGURE 1-1: TASK SCHEDULES

1.2 PURPOSE OF REPORT

This quarterly report is a record of the status and technical progress made on Contract NAS5-26546 during the period 31 July 1981 through 31 October 1981 by Stanford Telecommunications, Inc. and its two subcontractors:

- Fairchild Space and Electronics Company
- Space Communications Company

The purpose of the report is to inform scientific, engineering and administrative personnel of technical progress on the contract and the scientific and engineering results achieved.

1.3 BRIEF SUMMARY OF WORK

The objective of the contract is to initiate a series of system studies, operational assessments, and technology demonstrations that will culminate in a system requirements definition for a NASA Tracking and Data Acquisition System which satisfies NASA's Earth Orbiting Mission Requirements through the 1990's as a follow-on to the Tracking and Data Relay Satellite System (TDRSS) of the 1980's. This new system, called the Tracking and Data Acquisition System (TDAS), will represent a key element of the NASA End-to-End Data System of the 1990's. The function of this element will be to provide the required tracking and data acquisition interface between user accessible data ports on earth and the user's spaceborne equipment.

This contract represents pre-Phase A concept definition for the proposed TDAS. It covers a full range of planning activities, starting with user requirements studies and including architectural options, cost trade-offs, performance simulations, technology forecasts, frequency assignment requirement and constraints, RFI performance and other related matters.

1.3.1 Task Identification

There are 14 technical tasks and 3 subtasks which are listed below:

*1. User Community Characteristics
*2. Spacecraft Data System Architecture
*3. Mission Model
*4. User Ground Data System Architecture
5. Tracking and Data Acquisition System (TDAS) Architecture
5A. TDAS Retrieval
6. User Communications Technology Assessment
7. TDAS Communications Technology Assessment
8. User/TDAS Operational Aspects
9. Executive Summary Report
*10. Frequency Plan and Radio Interference Model Development
*10A. Frequency Management
11. Threat Model Development/Security Assessment
*12. Upgrading the SAMSO Cost Model
*13. Viterbi Decoder/Simulator Study
*13A. Ku-Band Performance in the presence of RFI
*14. Deep Space Support

1.3.2 Summary of Work Performed

Task 1, User Community Characteristics, was completed during the quarter. A data base consisting of the characteristics of potential experiments was developed based upon surveys of the existing literature and discussions with various NASA organizations and program managers. This data base was formulated into a planning baseline for the 1990's time frame with generic experiments being added as appropriate. This baseline of plans was then screened to determine the experiments/missions of concern to TDAS. This screening was based upon the flight schedule, orbit parameters, TDRSS compatibility and whether the Shuttle is the vehicle. Forecast options were then formulated to reflect

* The tasks which were active during this quarter are indicated by an asterick.

budget options and vehicle options (i.e., free-flyers vs platforms). The scenario of experiments were then developed from this information. For each experiment in the scenarios, information was collected on the data distribution requirements, communication requirements and navigation requirements. In order to complete the TDAS User Community Characteristics, the suitability of various navigation systems to satisfy the navigation requirements was determined, the impact of the NASA End-to-End Data System (NEEDS) and the Application Data System (ADS) on data distribution was assessed, and the impact of operational aspects of the Shuttle, space platform and space stations was determined. A draft final task report will be issued.

Task 2, Spacecraft Data System Architecture, was initiated in the first quarter and continued during the reporting quarter. A forecast is now nearly complete for technology applicable to the 1990s in the areas of spacecraft sensor handling, navigation systems and approaches, and communication systems. Initial efforts were made to develop user spacecraft data system architectures and to estimate spacecraft size, weight and power needed for subsequent costing activities. Modifications were made to the System Performance Assessment Simulator to automate GPSS code generation in the Communications Traffice Simulator.

Task 3, Communications Mission Model, was initiated in the first quarter and continued during the reporting quarter. Four scenarios of mission models have now been developed, two for the NASA constant activity option and two for the increased activity option. The preliminary mission models were refined and upgraded by investigating the impact of detailed orbital requirements on the PUP loading and by examining the shuttle model used to estimate the number of simulteneous shuttles to be supported by TDAS. Also added was a military mission model defining the characteristics of certain military satellites operating in the TDAS time frame. Channel requirements to support mission data communication functions were assessed from the data rate and contact time information complied for each scenario. Upper and lower bounds on required TDAS data throughput and the number of multiple and single access channels were estimated. A baseline set of communication model parameters was set up for four TDAS architectural options in terms of:

- Frequency Plans that specify center frequencies and bandwidths for each channel type, and

- Link Budgets that validate transmit EIRPs, antenna G/Ts and other link parameters based on required data rates and BER performance constraints.

Task 4, User Ground Data System Architecture, was initiated as scheduled during the last month of the reporting period. Work will continue through July of 1982. The initial steps in the quarter began the generation of requirements for the user ground system.

Task 10, Frequency Plan and Radio Interference Model Development, was initiated in the first quarter and continued during the reporting quarter. Two milestones were achieved during the reporting period. A TDAS frequency utilization plan was completed for each TDAS architectural option; and an RFI model for each frequency band was developed. These efforts included preliminary consideration of survivability and robustness issues, with the goal of coordinating overall completion of the task in November.

Task 11, Threat Model Development/Security Analysis, was initiated in the third month of the reporting period. The initial effort was to identify the particular links and frequencies for which the Threat Model Development would be accomplished. Following that there began a review of the threat analysis performed under the Satellite Control Satellite (SCS) study performed by STI/Ford for the Air Force. SCS is a concept for a relay satellite system for military communications which has considerable functional similarity to TDAS. The SCS findings have been summarized and will be used as input to the TDAS Threat Model. Work on the Security Analysis portion of the task was not initiated during the reporting period.

Task 12, Upgrading the SAMSO Cost Model, was initiated late in the first quarter and continued during this reporting quarter. Documentation was reviewed on the (SAMSO) Unmanned Satellite Cost Model (5th Ed.) and the GSFC Spacecraft Cost Model (1980). Agreement was reached on four satellite systems in various weight classes for subsequent cost comparisons. A data collection was initiated to obtain cost model inputs (subsystems weights, solar array output power, etc.) for each spacecraft. The collection effort was completed by the end of the reporting quarter.

Task 13, Viterbi Decoder/Simulator Study, was initiated by Task Assignment dated May 13. The initial effort involved a revision and some performance comparison for the Viterbi Hardware Simulator (Linkabit) and the Viterbi Software Simulator (Stanford Telecommunications, Inc.).

Verification of the duality of the software simulation model and hardware test equipment has been completed. Utilization of the software simulator is being performed in two generic categories. These categories consist of measuring false alarm probability on the Viterbi decoder synchronization output under pulsed RFI scenarios for cases with,and then without the interleaver operating. For the scenarios with an operational interleaver a probabilities model for environments is being utilized. For the scenario without an interleaver, a deterministic model is being utilized which places an RFI burst of known duration in a known time position and measures the effects.

Task 14, Deep Space Support, was initiated late in the first quarter. Only preliminary planning of the task effort has been performed pending JPL efforts to update their space mission planning models.

1.4 CONTENTS OF REPORT

The contents of this report covers this introduction; a main text (Section 2) arranged in T/A numbered order which describes all task activities in the reporting period; and a description (Section 4) of the planned task activities for the next reporting period.

Conclusions and recommendations are also provided.

This report covers task activities on the following tasks:

- Task 1: User Community Characteristics
- Task 2: Spacecraft Data System Architecture
- Task 3: Communication Mission Model
- Task 4: User Ground Data System Architecture
- Task 5: TDAS System Architecture (1)
- Task 5A: TDAS Retrieval (1)
- Task 10: Frequency Plan & RFI Model
- Task 10A: Frequency Management
- Task 11: Threat Model Development/Security Assessment
- Task 12: Upgrading the Space Cost Models
- Task 13: Viterbi Decoder/Simulator Study
- Task 14: Deep Space Support

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(1) NOTE: These new tasks are covered only under the program for the next reporting period (Section 4).

SECTION 2

TASK REPORTS

This section refers to all Task Assignments under the contract, for completeness in progress reporting. However, only 10 of the tasks were actually scheduled for work activity during the quarter. Progress of these active tasks is reported here in detail.

2.1 TASK 1 - USER COMMUNITY CHARACTERISTICS

Task 1, User Community Characteristics, is concerned with developing two scenarios of experiments that will form the basis for generating alternative sets of mission models for the Tracking and Data Acquisition System (TDAS) in the 1990's time frame. To accomplish this, a Baseline of Plans within the aerospace community was developed for the 1990's time frame. Navigation and communication requirements were identified and a set of alternative forecast options developed. This information was then used to generate the scenarios of experiments.

Work on Task 1 started upon award of contract and was essentially complete by the end of August. See the STI "First Quarterly Technical Progress Report" for a good description of task activities.

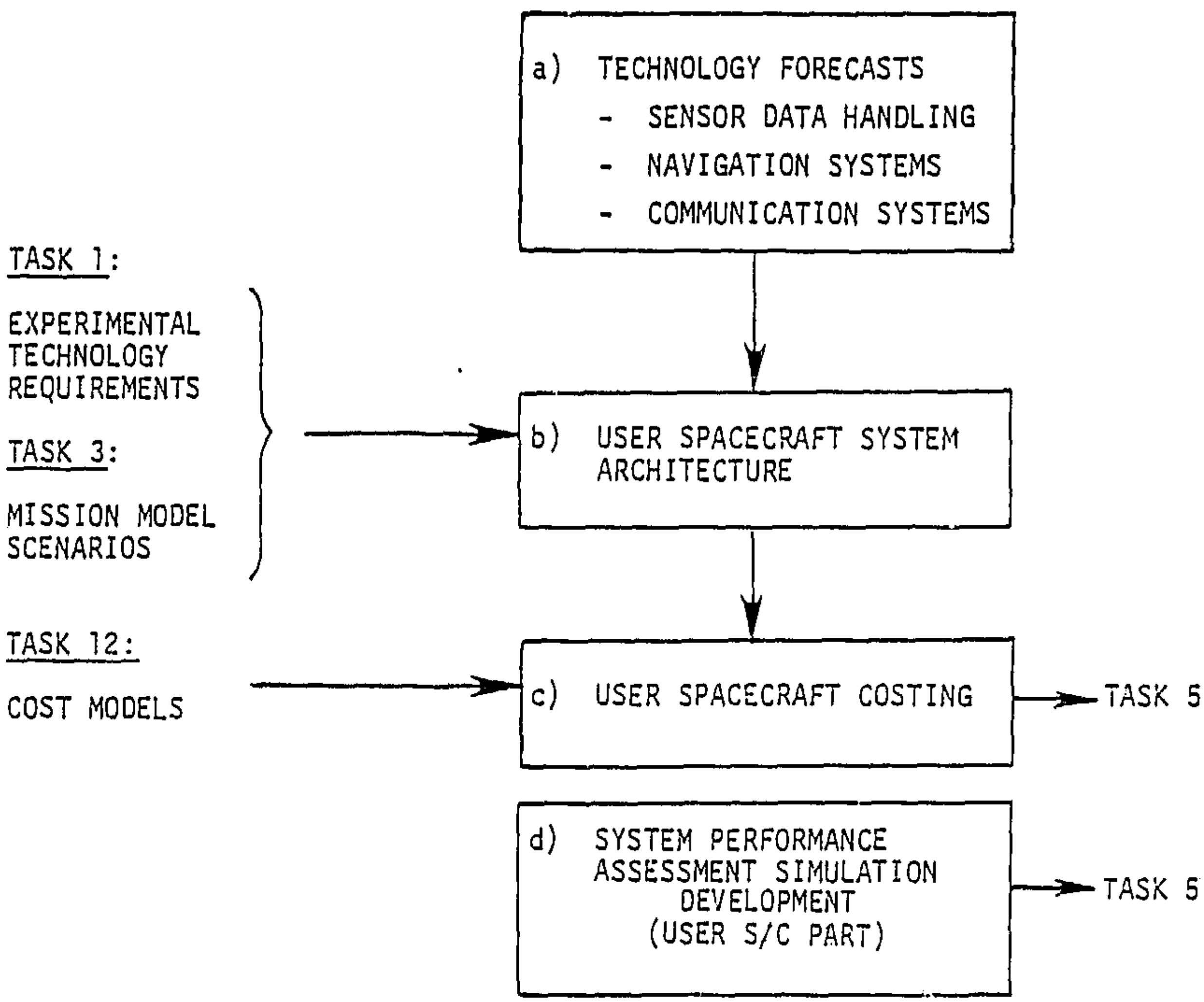
2.2 TASK 2 - SPACECRAFT DATA SYSTEM ARCHITECTURE

This task is concerned with defining data system architectures for potential TDAS user spacecraft and estimating the corresponding spacecraft costs for use in later tasks that address cost trade-offs among other TDAS elements. Figure 2.2-1 presents a block diagram of the major task elements and the interface with other TDAS study tasks.

The spacecraft data system architectures will be defined based on mission constraints and related technology forecasts for the 1990s. Spacecraft costs for each mission will be estimated using cost model information developed in

FIGURE 2.2-1

TASK 2 ELEMENTS AND INTERFACES



Task 12. In addition, part of an overall System Performance Assessment Simulation (SPAS) program dealing with user spacecraft data system performance will be developed.

This subsection relates the activities undertaken in this task in the current reporting quarter.

2.2.1 Technology Forecast - Task 2a

A forecast is being made of technology applicable to the 1990s in the areas of spacecraft sensor data handling, navigation systems and approaches, and communication systems. The forecast also considers other factors which could affect the user spacecraft interface with the TDAS such as elements of the NASA End-to-End Data Systems (NEEDS) concept.

2.2.1.1 Sensor Data Handling Technology Forecast

The technology forecasting activity in the sensor data handling area uses a variety of pertinent information sources in conjunction with requirements and constraints. This is summarized in the detailed plan of attack shown in Table 2.2-1.

The technology forecasts for the following components have been completed:

- Data Compression
- On-Board Computers
- Mass Storage Systems
- Memories
- Coding Schemes
- Future Data Communication Methods
- Tape Recorders

A sample of the output is provided in Figures 2.2-2 and 2.2-3.

2.2.1.2 Navigation System Technology Forecast. The user requirements for navigation (orbit, time and attitude determination) to support anticipated space missions in the 1990s have been surveyed in Task 1. A forecast of the

TABLE 2.2-1

APPROACH FOR SENSOR DATA HANDLING TECHNOLOGY FORECAST

INFORMATION SOURCES

- TDAS BASELINE
- NAVIGATION TECHNIQUES
- NASA SPACE SYSTEMS TECHNOLOGY MODEL
- NASA PROGRAM PLANNING AND POSITION PAPERS
- NEEDS PROGRAM APPROACHES

REQUIREMENTS AND CONSTRAINTS

- TDAS BASELINE REQUIREMENTS
- NAVIGATION ACCURACIES

ACTIVITY

1. INVESTIGATE DATA HANDLING APPROACHES INCLUDING:
   - PACKETIZING DATA
   - DATA COMPRESSION
   - ONBOARD DATA PROCESSING
   - REMOTE S/C PROCESSING BY USERS

2. PROJECT ONBOARD COMPUTER THRUPUT AND MASS STORAGE CAPABILITIES TO REDUCE TRANSMISSION DATA RATE

3. INVESTIGATE FUTURE DATA COMMUNICATION METHODS:
   - NEW CODING SCHEMES FOR HIGHER CODING GAIN
   - SECURE AND SPREAD SPECTRUM COMMUNICATION

4. TECHNOLOGY SURVEY THRU INDUSTRY CONTACT OF:
   - OB PROCESSORS
   - MEMORIES
   - TAPE RECORDERS
   - SENSORS

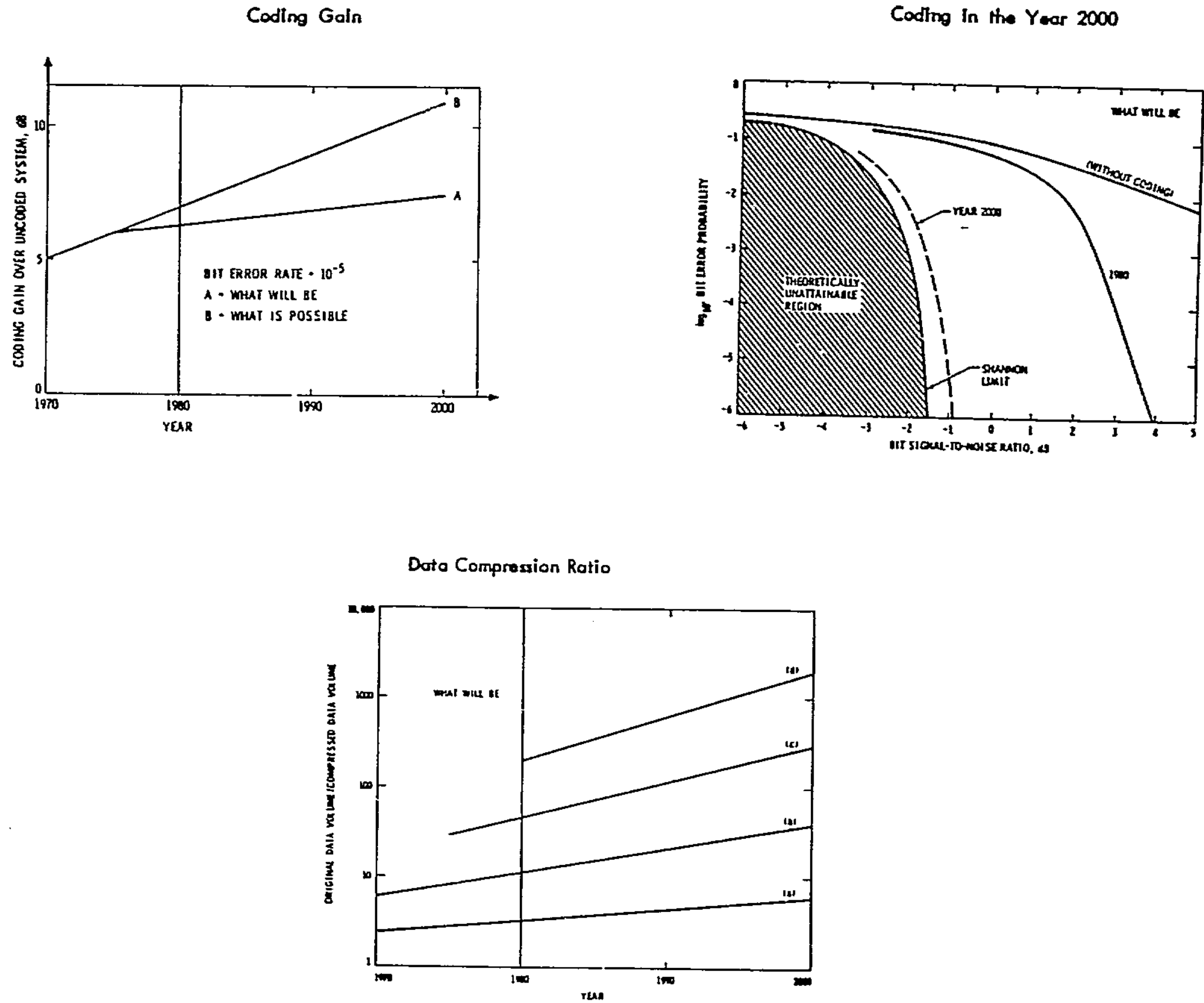


FIGURE 2.2-2: FORECAST OF DATA COMPRESSION AND CODING CAPABILITIES

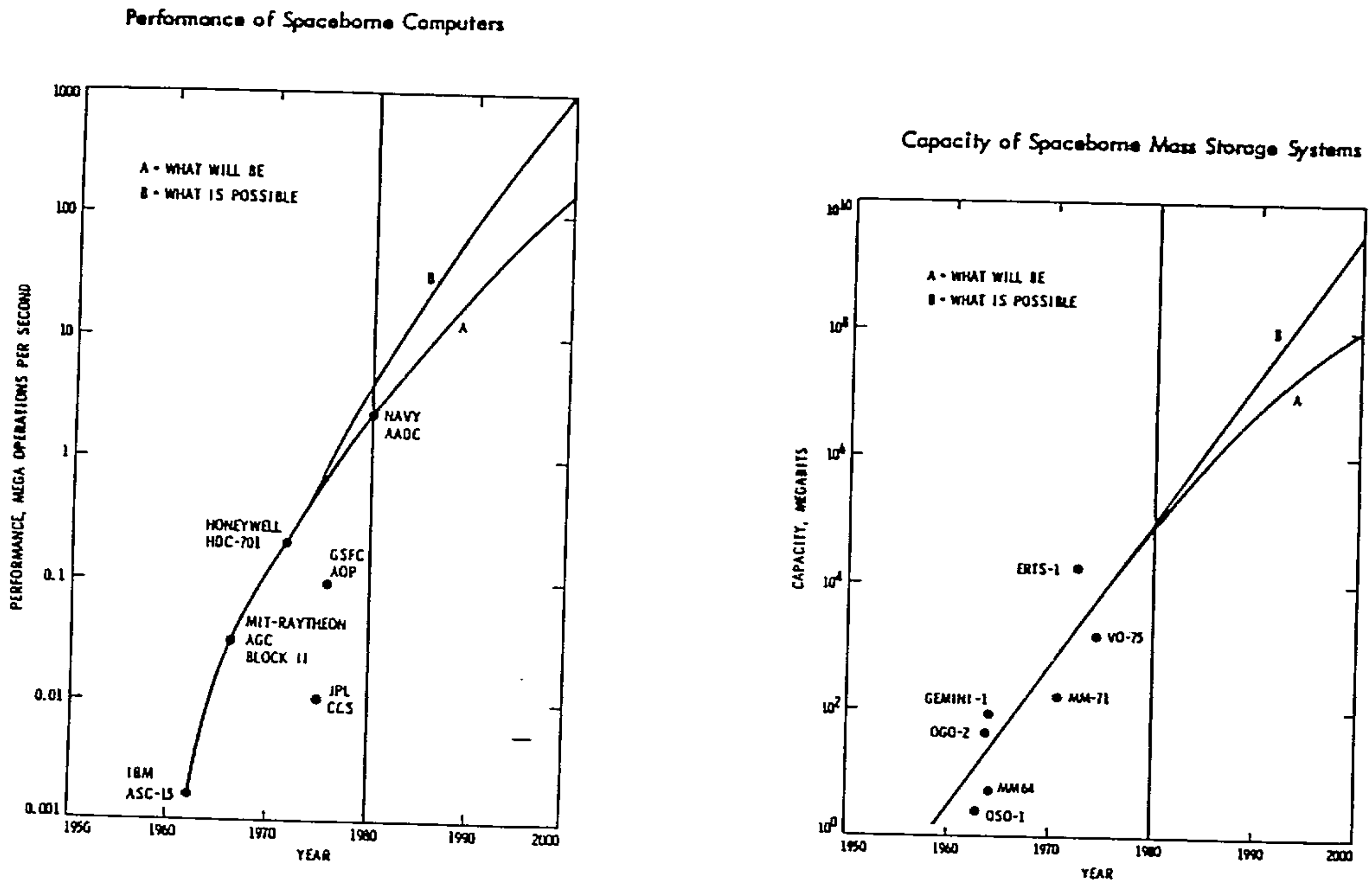


FIGURE 2.2-3: FORECAST OF SPACEBORNE COMPUTER AND MASS STORAGE CAPABILITIES

technology which could potentially satisfy these requirements will be a key input to defining spacecraft data system architectures. This task will provide a forecast of applicable navigation technologies and a comparison with anticipated user requirements.

The forecasting is based on information derived from various sources including NASA and industry contacts and published literature. The following paragraphs present a summary of the forecasts for the three navigation functions.

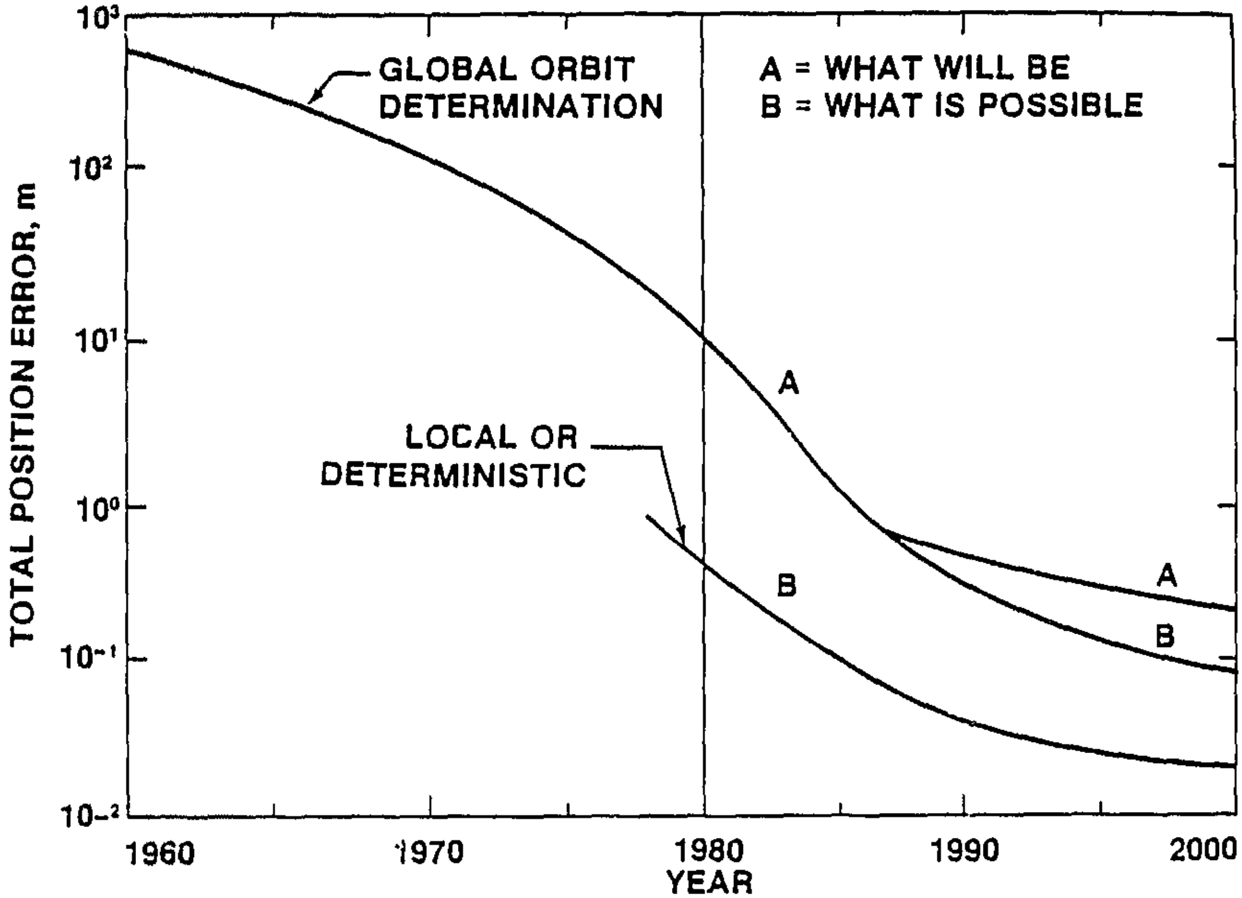
2.2.1.2.1 Orbit Determination Technology. In 1976, the Hearth Study, Ref. [64] made the forecast of 3D location accuracy of an earth orbiting satellite shown in Figure 2.2-4. It assumed two types of orbit determination (OD) technology: global or statistical OD and local or deterministic OD. While both forecasts now appear to be quite optimistic to employ generally, especially for low earth orbits, they provide a frame of reference for comparing systems or approaches in planning or development.

A number of candidate technologies which could potentially support user orbit determination are listed in Table 2.2-2 according to the particular measurement technology involved. Some would be appropriate for autonomous (on-board) navigation and the rest for ground-supported orbit computation. All would utilize so form of statistical (global) orbit determination technique except for GPS and possibly the optical techniques (depending on the state observability achieved with the measurement sets employed).

A forecase of orbit determination accuracies has been developed for satellites operating at TDAS user altitudes. This is shown in Figure 2.2-5 for several of the alternative approaches. A range is shown to reflect uncertainities due to factors such as user orbit altitude range (drag effects), measurement schedule and/or potential improvements in the orbit determination technique with time (see Table 2.2-3).

In the TDRSS era, for example, the 3D position error based on the two-way range/doppler, ground-computed orbit technique ($TDRSS_2$) should be ~50-250 m(1σ) initially. Subsequently, with moderate reductions due to modeling improvements and GSFC computer hardware and software improvements, the accuracy could improve to the

FIGURE 2.2-4: FORECAST OF POSITION ACCURACY OF EARTH ORBITING SATELLITES (HEARTH STUDY 1976)



Global Orbit Determination is the computation of the state vector from sets of measurements in which no single measurement uniquely determines the complete state. Outside of a tracking arc, position estimates are derived via state vector propagation. This method is used with STDN.

Deterministic Orbit Determination is the computation of state vector using short arcs of multistation data in which the current state is uniquely determined from a single measurement set. This is used with NAVSTAR/GPS.

TABLE 2.2-2: CANDIDATE TECHNOLOGIES FOR USER ORBIT DETERMINATION

MEASUREMENT TECHNOLOGY	SYSTEM IMPLEMENTATION*		MEASUREMENT TYPES				ORBIT COMPUTATION			
	EXISTING/IN DEVELOPMENT	POTENTIAL	RANGE		DOPPLER	ANGLE	LOCATION		TYPE**	
			1 WAY	2 WAY			ONBOARD	ONGROUND	D	S
RF SIGNAL DETECTION	GPS		x		x		x		x	
	$TDRSS_1$				x			x		x
	$TDRSS_2$			x	x			x		x
		TDAS	x		x		x			x
LASER/RADAR REFLECTION	TLSR			x				x		x
		SLS		x			x			x
		RADAR(TBD)		x			x		x	x
OPTICAL	SS-ANARS					x	x		x	x
	AONS					x	x		x	x
	SHADS					x		x	x	x

* SS-ANARS - Space Sextant-Autonomous Navigation & Attitude Reference System (DOD)
AONS - Automated Optical Navigation System (NASA/JPL)
SHADS - Stellar Horizon Atmospheric Dispersion System (DOD)
TLRS - Transportable Laser Ranging System (NASA)
SLS - Spaceborne Laser Ranging System (NASA)

** D - Deterministic O.D.
S - Statistical O.D.

FIGURE 2.2-5: FORECAST OF ORBIT DETERMINATION ACCURACY*

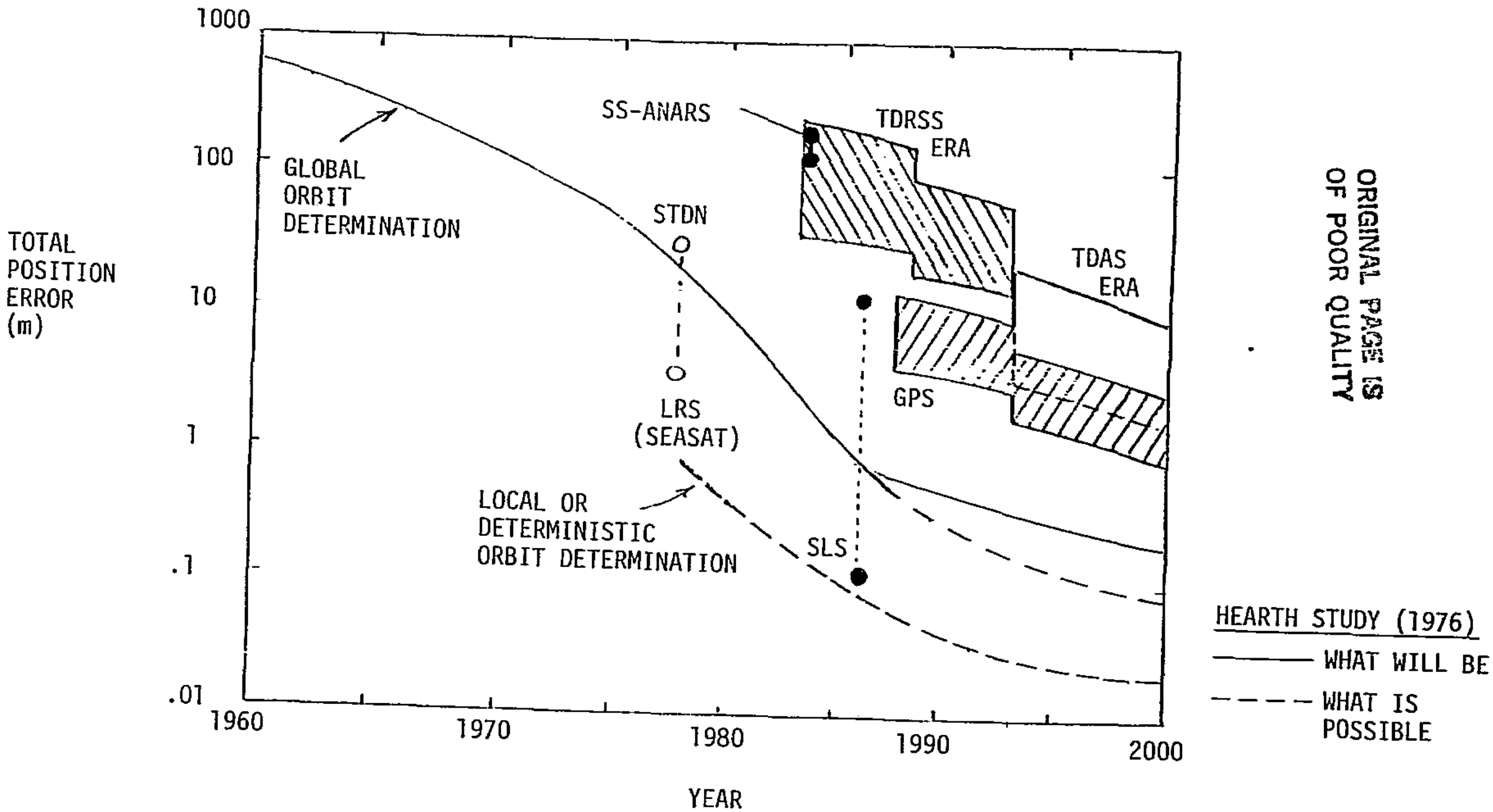


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TABLE 2.2-3: KEY ELEMENTS AFFECTING STATISTICAL ORBIT DETERMINATION TECHNIQUES VIA TDRSS/TDAS

KEY ELEMENTS		IMPLEMENTATION TECHNIQUE		POTENTIAL IMPROVEMENTS
		ONBOARD	GROUND	
MODELLING PARAMETERS	- GRAVITATIONAL CONSTANT	X	X	~2:1 EARLY '80s.
	- GEOPOTENTIAL HARMONICS	X	X	~10:1 LATE '80s.
	- ATMOSPHERIC DRAG	X	X	
	- SOLAR PRESSURE	X	X	
	- REFRACTION		X	
	- GEODETICS		X	
MEASUREMENTS	- 1 WAY RANGE/DOPPLER			INDEPENDENT NAVIGATION SIGNAL FOR
	• DATA RATE/DUTY CYCLE	X		NEAR-CONTINUOUS TRACKING.
	- 2 WAY RANGE/DOPPLER			GROUND STATION RECEIVER PERFORMANCE
	• DATA RATE/DUTY CYCLE		X	(RANGE BIAS & NOISE).
SYSTEM ELEMENTS	- SATELLITE LOCATIONS	X	X	$\geq$10:1 FOR TDRS LOCATIONS WITH VLBI.*
	- TRACKING STATION		X	
	- COMPUTATIONAL RESOURCES			
	• MICROPROCESSORS	X		$\geq$10:1 INCREASE IN OPNS/SEC BY 1990.*
	• MAINFRAME HARDWARE		X	MAJOR REPLACEMENT AT GSFC BY EARLY '30s.
	• SOFTWARE		X	MAJOR UPGRADE AT GSFC BY LATE '80s.

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* OVER 1980 CAPABILITY OR KNOWLEDGE

15-75 m range by the early 1990s. In the TDAS era, a further reduction to the 5-25 m level may be achievable based on: an independent navigation signal added to the TDAS satellites for nearly continuous, high accuracy on-board tracking; improvements in ground-supported orbit determination; use of VLBI for higher accuracy TDAS satellite tracking (5-10 m).

Orbit determination accuracy with GPS is expected to be in the 5-15 m range initially (late '80s). This should also improve, reaching perhaps, the 1-3 m level by the mid 1990s if improvements such as a full 24 satellite constellation, higher power navigation signal, upgraded satellite clocks and user receiver technology advances are achieved.

Laser/Radar ranging techniques which achieve measurement accuracies in the 1-2 cm range can be used for determining satellite locations with accuracies in the sub-meter range over orbit areas where sufficient measurements are available. Since this is dependent on the availability and deployment of retro-reflectors, these techniques may be used in conjunction with other techniques to support missions which have stringent accuracy requirements only on altitude.

2.2.1.2.2 Time Determination Technology. The technology for time determination both in conjunction with autonomous (onboard) orbit determination or ground-supported time transfer via satellite relay has been assessed. The results of a current NASA program to develop an autonomous spacecraft clock (ASC) have also been reviewed.

Two autonomous and two ground-supported alternatives for time determination are listed in Table 2.2-4. In the autonomous cases the user derives its clock bias as an integral part of the orbit computation process. Time determination accuracy (in nanoseconds) will be approximately of the same order as the orbit determination accuracy (in ft.). A forecast is shown in Table 2.2-4 based on the data in Figure 2.2-5.

In the ground-supported cases the time corrections are derived from either one-way or two-way transmissions as currently planned with TDRSS. In the two-way technique time determination accuracy depends on the uncertainty in corrections for equipment

TABLE 2.2-4

ALTERNATIVES FOR TIME DETERMINATION

SYSTEM IMPLEMENTATION			APPROACH	ACCURACY (μsec)	
TYPE	EXISTING/IN DEVELOPMENT	POTENTIAL		1987	1995
AUTONOMOUS	GPS		USE GPS NAVIGATION SIGNAL AND ESTIMATE CLOCK OFFSET STATE ALONG WITH SATELLITE POSITION AND VELOCITY.	<.02	<.01
		TDAS	SAME AS ABOVE EXCEPT USE TDAS INDEPENDENT NAVIGATION SIGNAL.	—	<.03
GROUND-SUPPORTED	$TDRSS_1$		GROUND INITIATES 1-WAY TRANSMISSION; USER OBTAINS CLOCK CORRECTION FROM OFFSET IN REFERENCE TIME TAG AFTER CORRECTING FOR PATH DELAY.	1-3	0.1-0.3
	$TDRSS_2$		GROUND INITIATES 2-WAY TRANSMISSION AND DETERMINES OFFSET IN USER REFERENCE TIME TAG FROM CENTER OF TRANSMISSION INTERNAL; THEN UPLINKS CORRECTION TO USER.	<.10	<.05

and propagation errors and ground clock errors. These are expected to be $\leq$ 50 ns for TDRSS and could be reduced with tighter specifications on equipment and clocks if necessary.

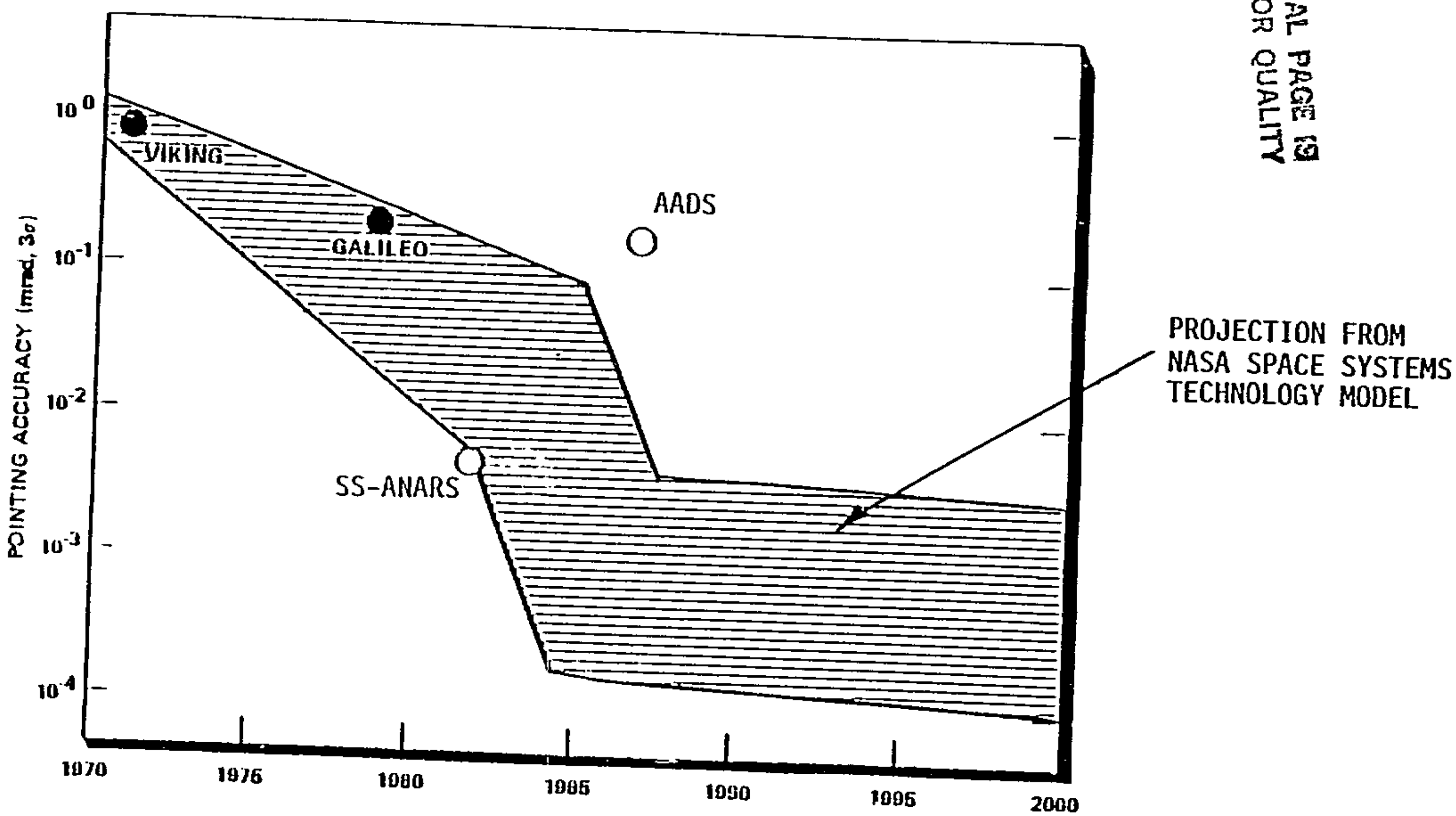
In the one-way technique accuracy depends on uncertainties in corrections for equipment and propagation errors as well as the relay satellite to user path delay which is a function of satellite location uncertainty. In the TDRSS era, users with a position accuracy of 0.3-1.0 km should achieve a one-way time transfer accuracy within 1-3 μs. Tighter specifications on equipment and better position accuracy (e.g. < 30-100 m) could potentially improve this to the 0.1-0.3 μs level.

2.2.1.2.3 Attitude Determination Technology. The technology for autonomous stellar-based attitude determination has been addressed. This includes the results of NASA efforts to develop and demonstrate a propotype autonomous onboard attitude determination system (AODS). Another development reviewed was the Space Sextant-Autonomous Navigation Attitude Reference System (SS-ANARS) mentioned above.

The attitude determination accuracy capabilities for each system are compared in Figure 2.2-6 with a forecast of pointing control accuracy obtained from the NASA Space Systems Technology Model. Future developments with CCD sensor technology are anticipated to yield a 10:1 improvement in image resolution. Since the forecast in Figure 2.2-6 is indicative of this trend it was adopted as the forecast for attitude determination accuracy in the TDAS era.

2.2.1.3 Communications System Technology Forecast. In the area of communication technology forecasting, the user spacecraft communication equipment technologies which can be assumed for generating alternative TDAS architectures are being forecasted. The objective is to forecast the following communication equipment technologies:

FIGURE 2.2-6: FORECAST OF
INSTRUMENT POINTING CONTROL ACCURACY (3σ)
(STELLAR REFERENCED)



RF TECHNOLOGY

1. ANTENNAS
2. HPA'S
3. LNA'S
4. RF FILTERS
5. DIPLEXERS/CIRCULATORS
6. FREQUENCY CONVERTERS
7. PHASE LOCKED LOOPS
8. FREQUENCY SYNTHESIZERS

BASEBAND TECHNOLOGY

1. MODEMS
2. CODECS
3. MULTIPLEXERS/DEMULTIPLEXERS
4. SYNCHRONIZERS
5. SEQUENCE GENERATORS
6. CODE-LOCK LOOPS
7. INTERLEAVERS/DEINTERLEAVERS
8. SOURCE & CHANNEL ENCODERS

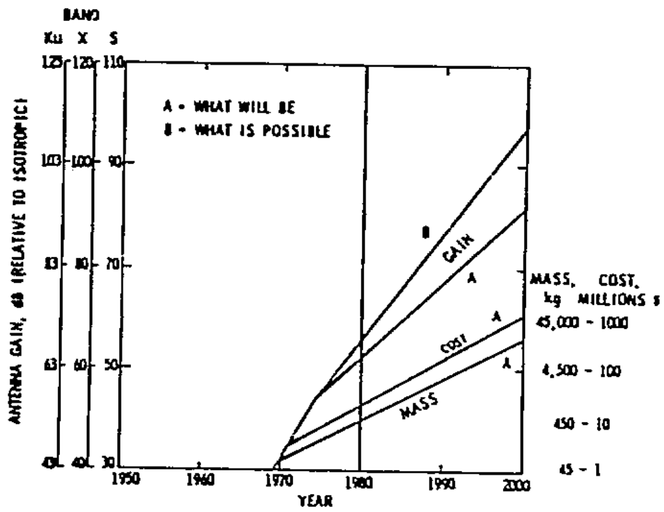
Thusfar, about half of the RF technology items (1, 2, 3, 4, 7) and baseband technology items (1, 2, 6, 8) have been addressed. A sample of the output is provided in Figures 2.2-7 and 2.2-8.

2.2.2 User Spacecraft System Architecture - Task 2b

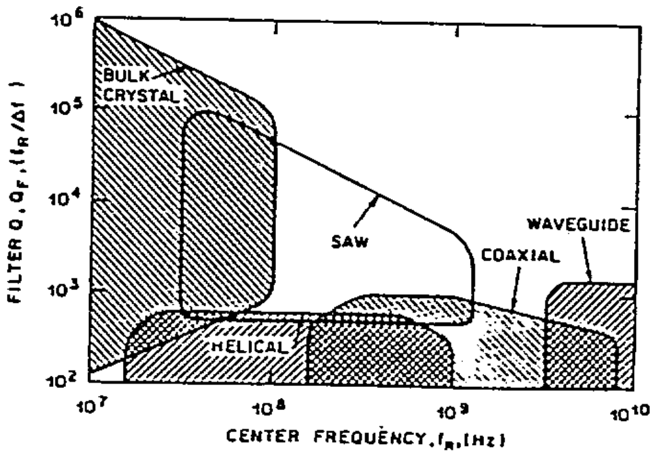
The activity on this subtask has been initiated and it is in its initial stages. The mission models have already been structured and, for the constraining missions out of these models the user spacecraft sensor data system architectures are being developed and spacecraft size, weight and power are being estimated.

Some examples of the user S/C Sensor data system architectures are provided in Figures 2.2-9 through 2.2-12.

Gain, Mass, and Cost of Geostationary Earth-Orbital Antennas for Space-to-Space Communication at S, X, and K_u Bands



Ranges of usefulness for various resonator filters.



Device Noise Temperature versus Frequency

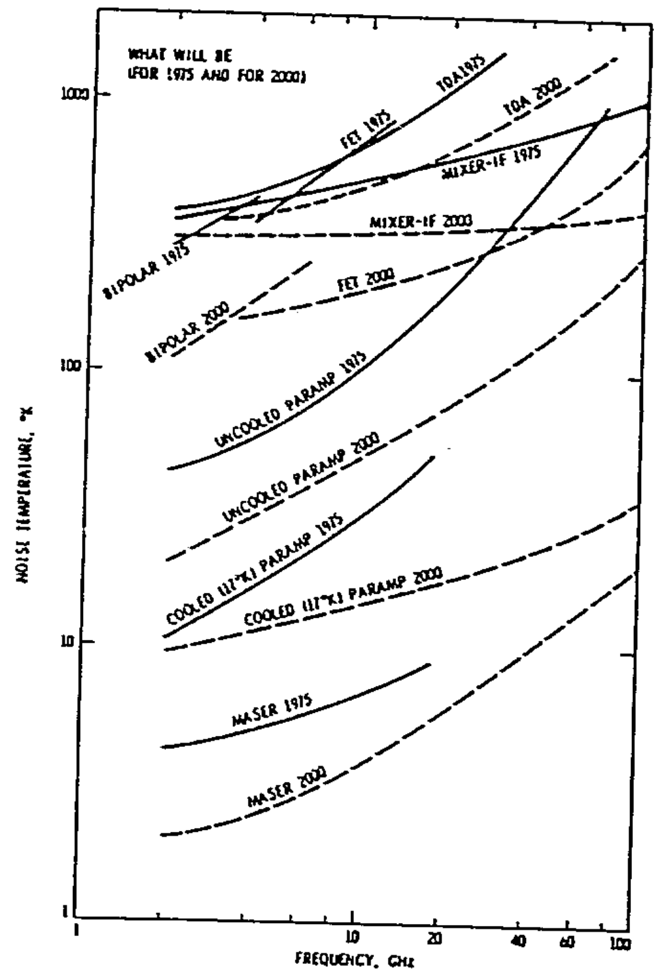


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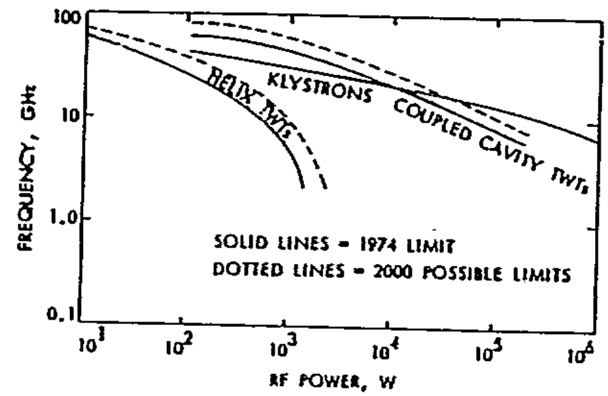
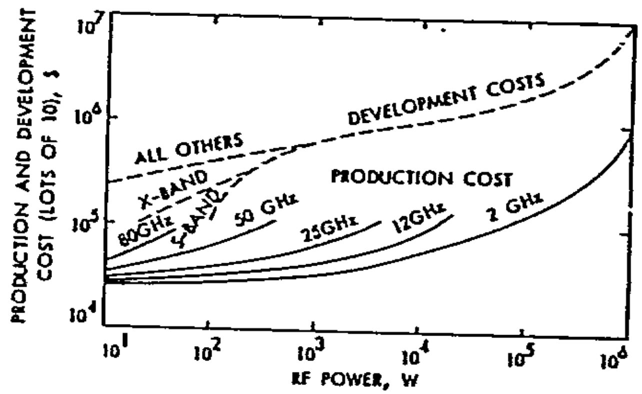
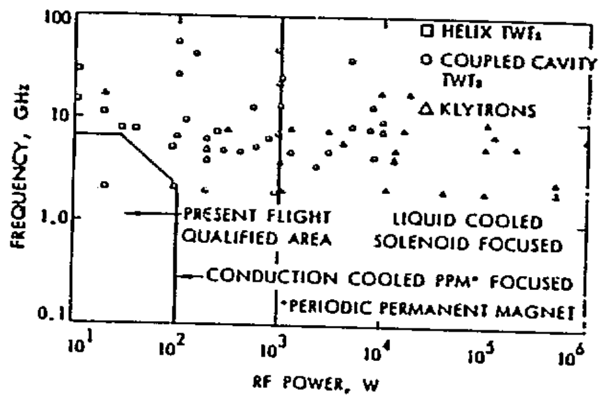
FIGURE 2.2-7: FORECASTS OF ANTENNA, LNA AND FILTER TECHNOLOGY



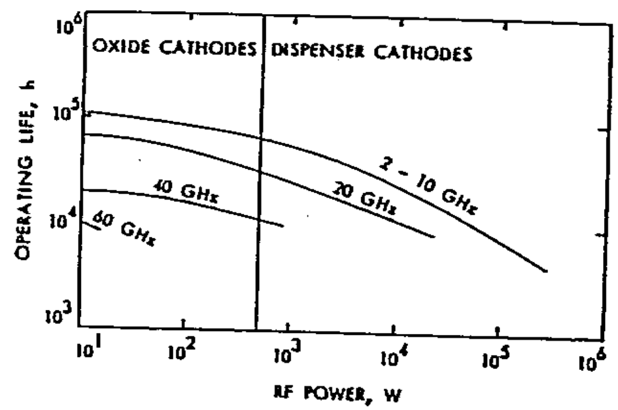
Maximum power-frequency characteristics of linear beam tubes



Electron tube cost versus rf power (flight quality)



Power-frequency characteristics of presently available tubes



3-dB life versus rf power for linear-beam tubes

FIGURE 2.2-8: FORECASTS OF HPA TECHNOLOGY

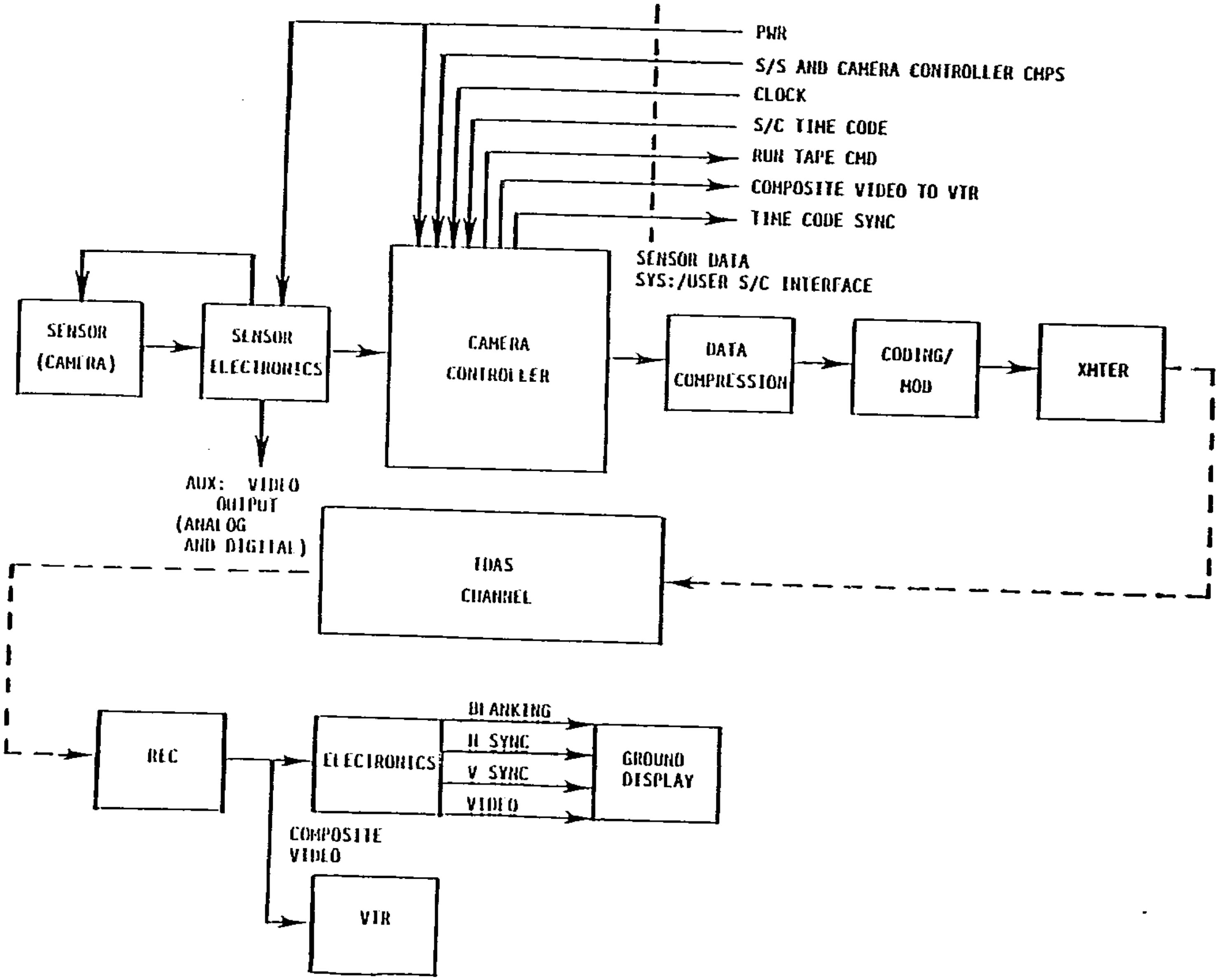
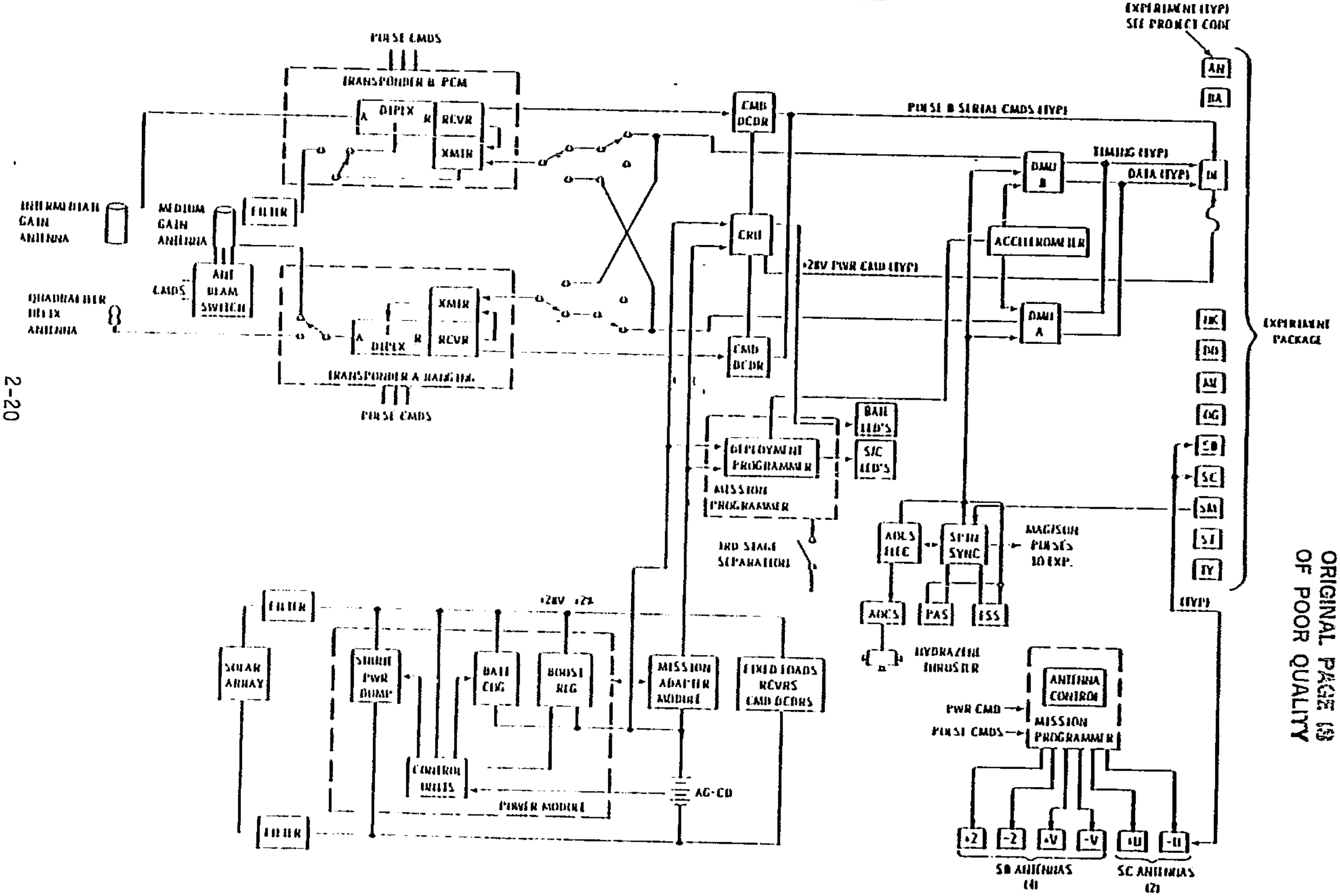


FIGURE 2.2-9: EXAMPLE OVERALL SENSOR DATA/COMMUNICATION SYSTEM*

FIGURE 2.2-10: ISEE-C ARCHITECTURE



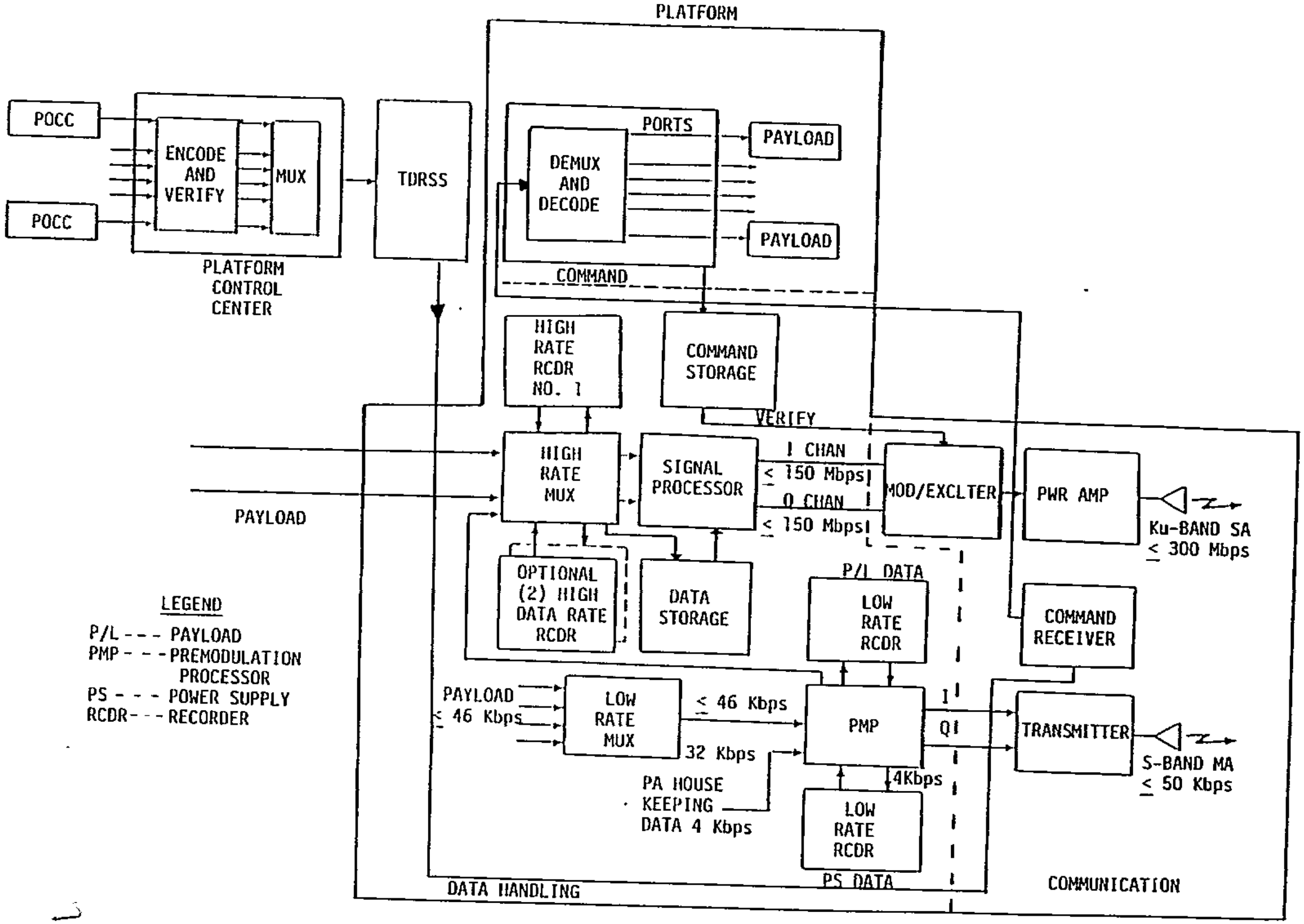
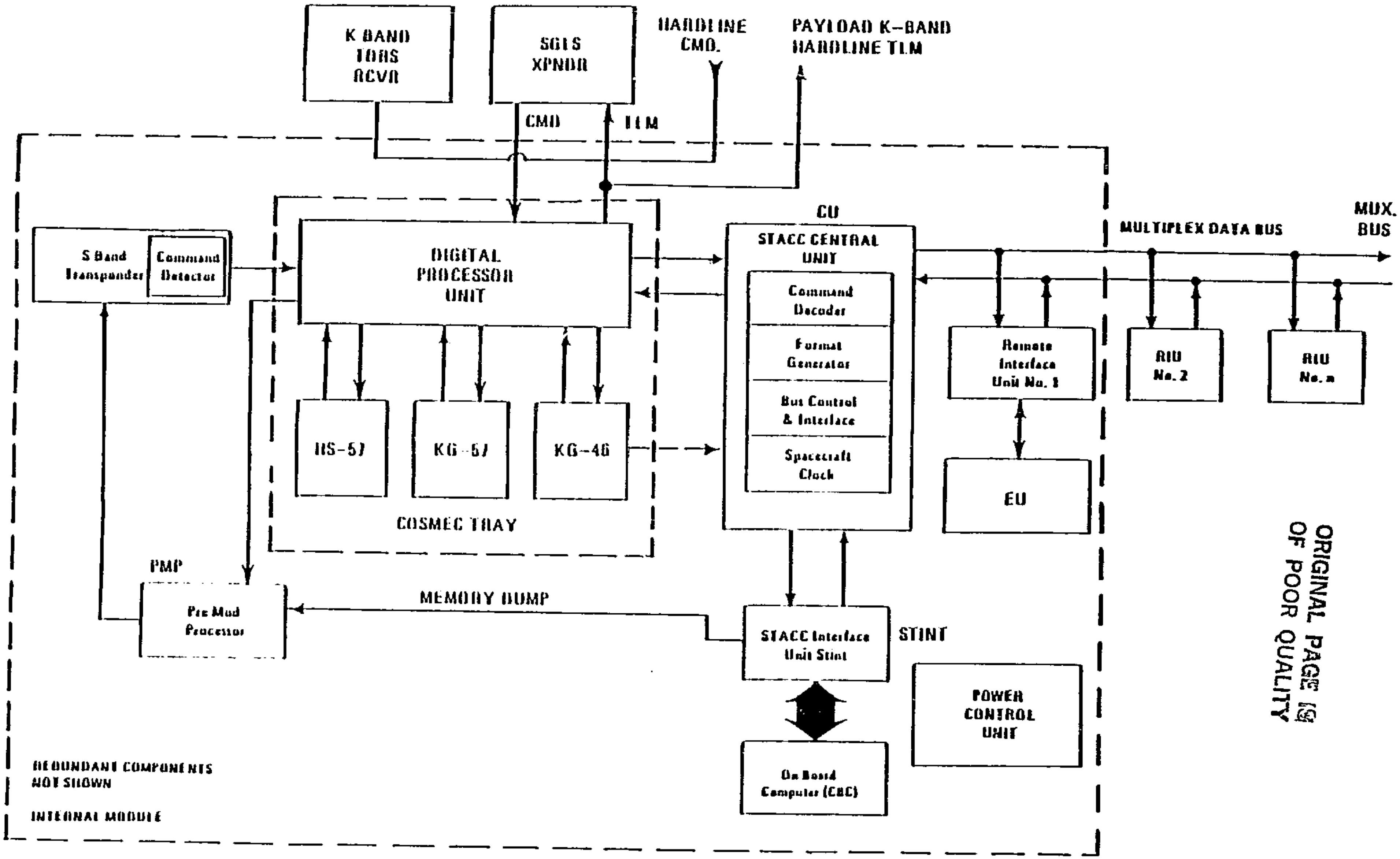


FIGURE 2.2-11: SASP COMMAND AND DATA HANDLING SYSTEM ARCHITECTURE

FIGURE 2.2-12: MMS ARCHITECTURE



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2.2.3 User Spacecraft Costing - Task 2c

There was no activity on this subtask in this reporting quarter.

2.2.4 System Performance Assessment Simulation (SPAS) Development (User S/C Part) - Task 2d

An overview diagram of SPAS which is to be used for evaluating system accessibility and throughput as a function of system parameters is shown in Figure 2.2-13. This subtask involves the development of the Communication Traffic Simulator (CTS) and Spacecraft Motion Simulator (SMS) which were described in the previous Quarterly Report. The other SPAS elements will be developed in conjunction with Tasks 4 and 5.

In this reporting period the activity involved an upgrade to the CTS module which models the scheduling and processing of TDAS forward and return link service intervals. This function was implemented via GPSS software which is well suited to simulation of queueing systems wherein discrete transactions move within the context of a multi-server, multi-path network. The upgrade incorporated in the CTS module now permits automatic generation of GPSS code from a predefined input file.

Typically, individual transactions (services) are modeled by a unique block of GPSS code which was previously entered by the simulation operator. This was manageable for short simulation and during testing. However, for long simulations with many system parameters being varied, automatically generating these dedicated sections of code (see Figure 2.2-14) significantly reduces programming errors as well as simulation time.

FIGURE 2.2-13: TDAS PERFORMANCE SIMULATOR

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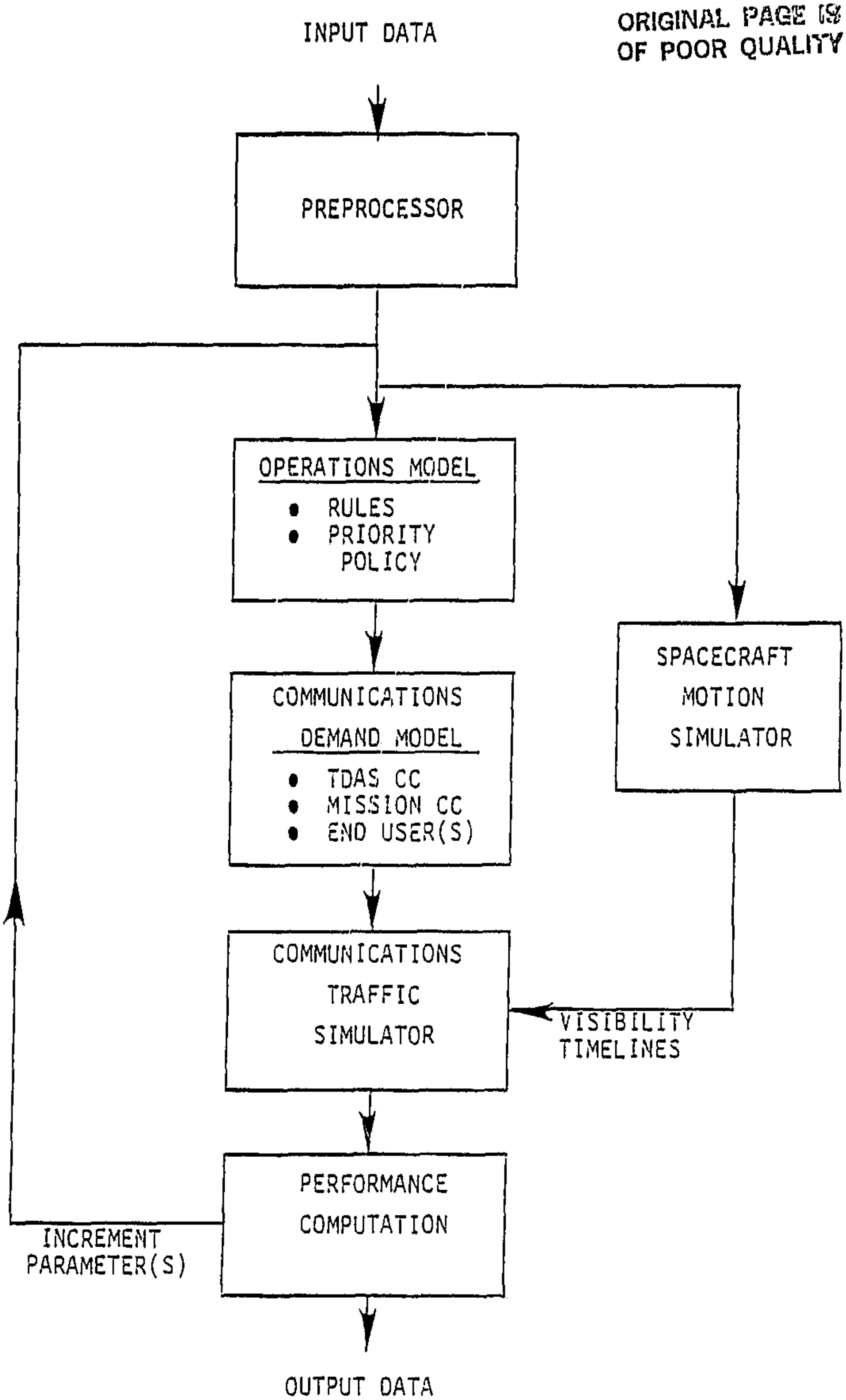

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TELECOMMUNICATIONS INC.

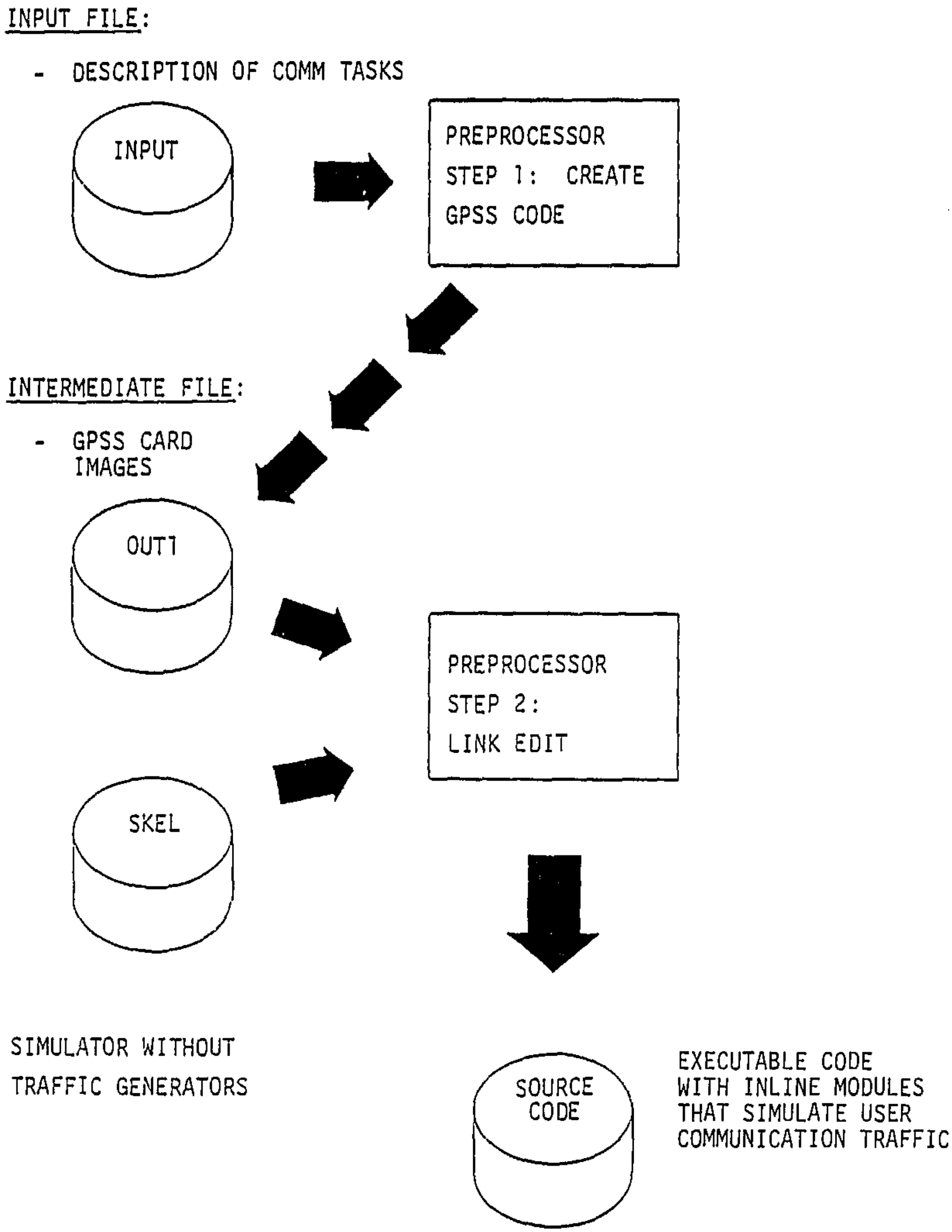

FIGURE 2.2-14: AUTOMATIC CREATION OF USAT TRAFFIC MODULES

2.3 TASK 3 - COMMUNICATIONS MISSION MODEL

This task is concerned with developing a parametric description of the communication channels required between the complex of spacecraft to be supported and the user ground data systems. Figure 2.3-1 presents a block diagram of the major task elements and the interface with other TDAS study tasks.

Several mission models will be defined by grouping experiments identified in Task 1 into scenarios of free flyers and space platforms/stations. A corresponding communication model will be developed to include all the useful mission-related parameters needed to perform system trade-off studies in later tasks. Examples of these parameters are EIRP, bandwidth, up-and downlink characteristics, contact hours per day, data rates, etc. The types of channels for navigation/tracking will also be considered and the results included in developing the communication models.

This section relates the activities undertaken in this task in the current reporting quarter.

2.3.1 Scenarios of Mission Models

Four scenarios of mission models have now been developed, two for the constant activity option (A1, A2) and two for the increased activity option (B1, B2). The space platforms and experiment loading percentage used in each scenario is summarized in Table 2.3-1. For illustration the timeline for Scenario A1 missions is shown in Figure 2.3-2.

The preliminary mission models were refined and upgraded by investigating the impact of detailed orbital requirements on the PUP loading and by examining the shuttle model used to estimate the number of simultaneous shuttles to be supported by TDAS. Also added was a military mission model defining the characteristics of certain military satellites operating in the TDAS time frame.

The communication characteristics of the missions in each scenario were compiled. These include the data rates (for dump and real time modes) and TDAS contact information. The characteristics for Scenario A1 missions are shown in Table 2.3-2.

FIGURE 2.3-1

TASK 3 ELEMENTS AND INTERFACES

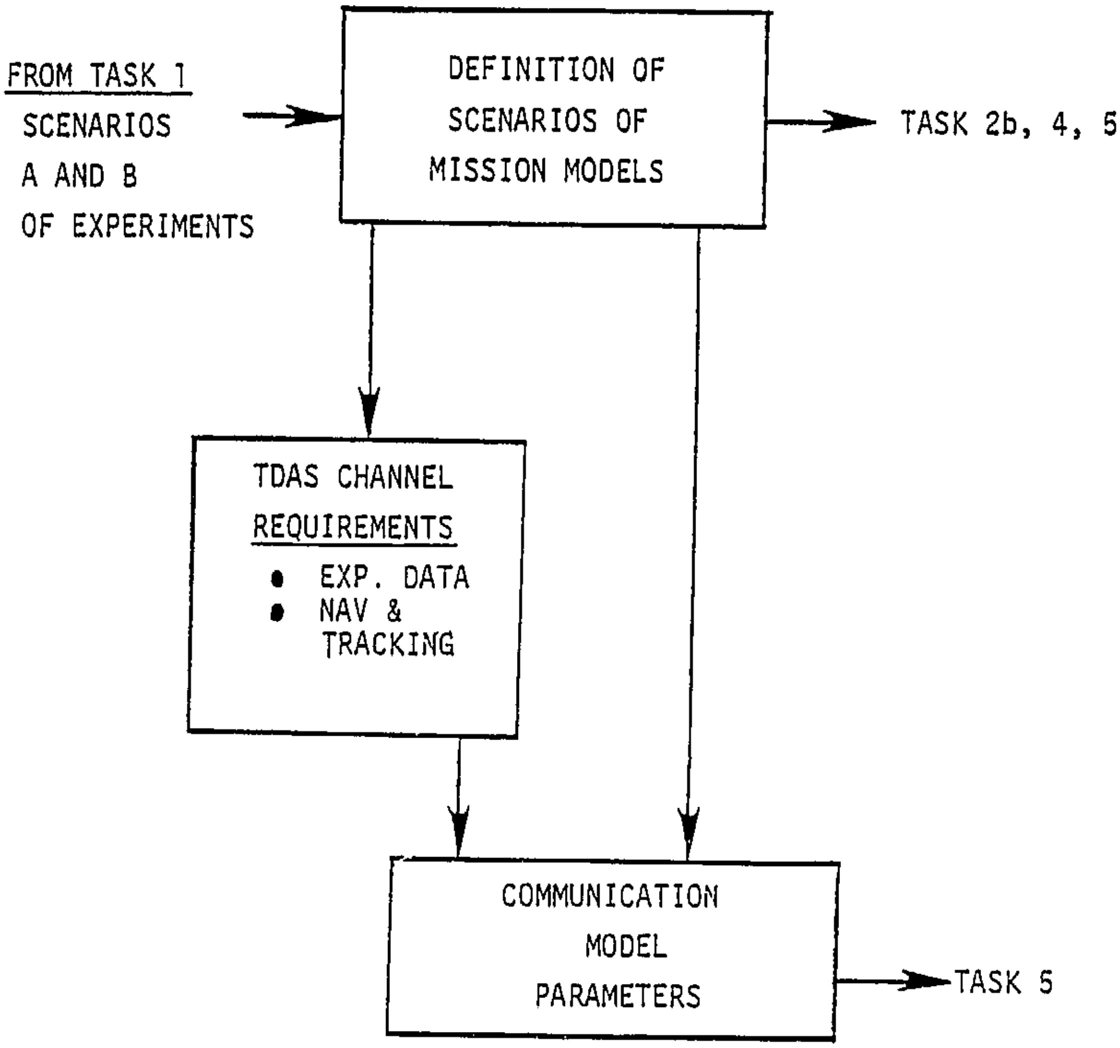

TABLE 2.3-1

SPACE PLATFORMS AND EXPERIMENT LOADING
IN MISSION MODEL SCENARIOS

Scenario	NASA Mission Activity	Experiment Loading* Platform #1	Platform #2	Platform #3
A1	Constant	75%	None	None
A2	"	"	66%	"
B1	Increased	96%	73%	"
B2	"	"	"	28%

*This assumes use of a second order Power Utilization Platform (PUP) with 6 berthing ports.

FIGURE 2.3-2

SCENARIO A1 OF MISSION MODELS

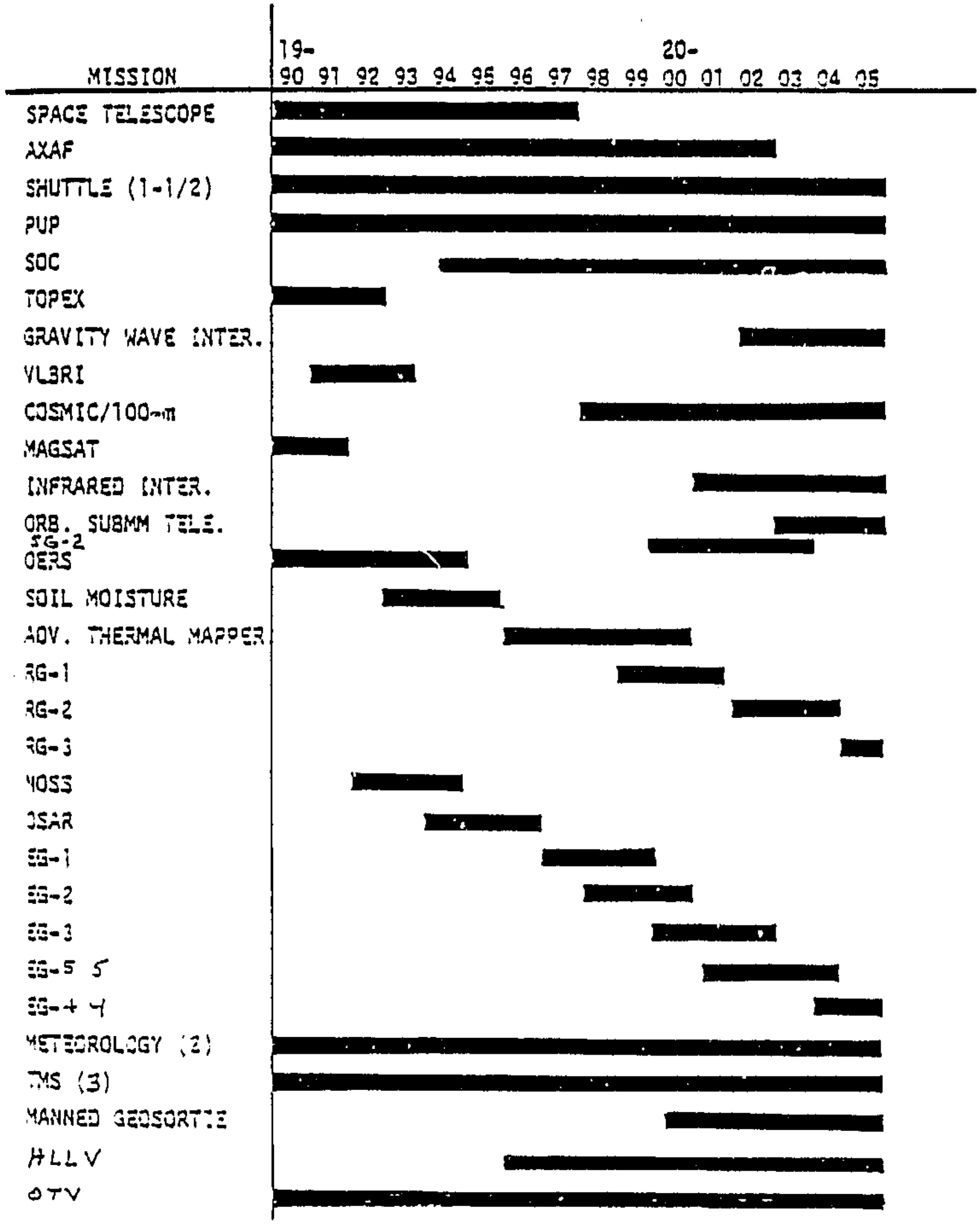

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TABLE 2.3-2

COMMUNICATION CHARACTERISTICS FOR MISSIONS IN SCENARIO A1

	RETURN LINK				FORWARD LINK			ORBIT	
Mission	Real Time Data Rate kbps	Dump Data Rate mbps	Contacts/ Day	Hours/ Contact	Data Rate kbps	Contacts/ Day	Hours/ Contact	Altitude km	Inclination °
Space Telescope	4	1.024	3	0.8	3	4	0.2	600	28.8
AXAF	40	1.0	1	2.8	3	4	0.2	450	28.5
Shuttle (1.5)	50,000	-	-	-	216	1	24	185-1,110	28.5-57 70-104
PUP	50	300	24	0.3	300	1	24	400	28.5
SOC	50	300	24	0.3	300	1	24	400	28.5
TOPEX	8	0.05	13	0.3	3	13	0.3	1,334	63.4
Gravity Wave Interfer.	1,000	-	-	-	3	4	0.2	250	Any
VLBRI	120,000	-	-	-	3	4	0.2	400-5,000	45
Cosmic/100-M	100	100	1	0.03	3	4	0.2	500	28.5
MAGSAT	12	0.064	4	0.2	3	4	0.2	300	97
Infared Interferometer	1,000	-	-	-	3	4	0.2	400-700	28-57
Orb. Submm. Telescope	1	0.01	1	0.03	3	4	0.2	1,000	Sun-Sync
S6-2	32,000	-	-	-	3	4	0.2	400	57
OERS	700,000	-	-	-	25	14	0.2	705	99
Soil Moisture	-	0.5	14	0.2	3	14	0.2	400-700	60-98
Adv. Thermal Mapper	-	0.2	16	0.3	3	16	0.3	620	97.8
RG-1	800,000	-	-	-	3	14	0.3	700	98
RG-2	800,000	-	-	-	3	14	0.3	700	98
RG-3	800,000	-	-	-	3	14	0.3	700	98
NOSS-Like	8	0.05	13	0.3	3	13	0.3	500	63
OSAR	-	200	14	0.3	4	14	0.3	790	Polar
EG-1	-	200	14	0.3	4	14	0.3	790	98
EG-2	8	0.05	13	0.3	3	13	0.3	500	63
EG-3	-	200	14	0.3	4	14	0.3	790	98
EG-4	-	200	14	0.3	4	14	0.3	790	98
EG-5	8	0.05	13	0.3	3	13	0.3	500	63
Meteorology (2)	665	2.66	10-11	0.2	3	12-14	0.2	830	98.7
T.M.S. (3)	15,000	15	0.13	24	2	0.13	24	1,000	Various
Manned GEO Sortie	-	1.5	0.25	168	3	0.25	168	LEO-GEO	Various
HLLV	16	-	-	-	2	1	24	200-500	Various
OTV	-	6	8	0.75	2	8	0.75	LEO-GEO	Various

2.3.2 TDAS Channel Requirements

Channel requirements to support mission data communication functions were assessed from the data rate and contact time information compiled for each scenario (such as Table 2.3-2). Upper and lower bounds on required TDAS data throughout and the number of multiple and single access channels were estimated.

2.3.2.1 Data Throughput. For each scenario bounds were computed on the aggregate data rate which TDAS would have to support over the planning period, 1990-2005. The range of forward and return link data throughput requirements is shown in Figure 2.3-3.

The upper bound assumes all users operate simultaneously at their highest data rate. The lower bound assumes all users that can, will operate real time (lowest data rate) and the rest will operate at the dump rate but with ideal scheduling (maximum interleaving of intermittent users). The gap between upper and lower bounds on the return link is due to several users with high dump rates but low duty cycles. An intermediate situation with all users operating at the highest rate but with ideal scheduling is indicated by the center curve in Figure 2.3-3.

2.3.2.2 Channel Multiplicity. While data throughput describes the aggregate capacity requirement, partitioning this into individual channels is also necessary. To determine the number of SA and MA channels it was necessary to define a maximum data rate to be supported by an MA channel. For the baseline model, this was chosen as 1.5 Mbps. Figure 2.3-4 shows the corresponding bounds on SA and MA channel multiplicity for the return link in Scenario A1. This indicates that the SA requirement is a critical parameter, since it drives the number of steerable TDAS antennas needed. For a three-satellite constellation this would be approximately 3-4 SA antennas per satellite depending on scheduling capabilities.

The sensitivity of SA channelization to the MA cutoff data rate was investigated. Figure 2.3-5 illustrates the results for Scenario A1 in a peak year, 2002. For cutoff data rates less than 1 Mbps, there is no possibility of satisfying user

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FIGURE 2.3-3

TDAS AGGREGATE FORWARD AND RETURN LINK DATA RATES (SCENARIO A1)

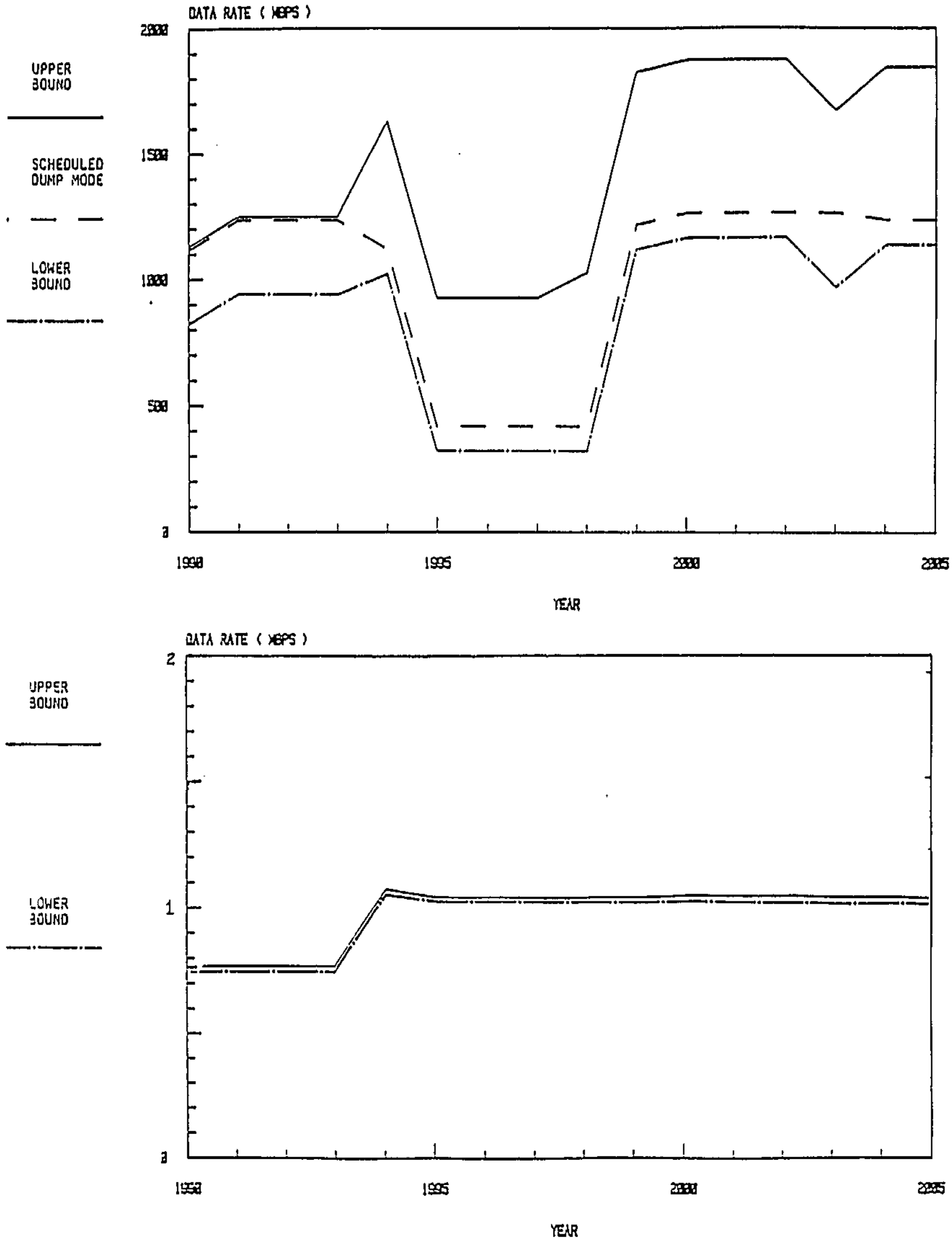

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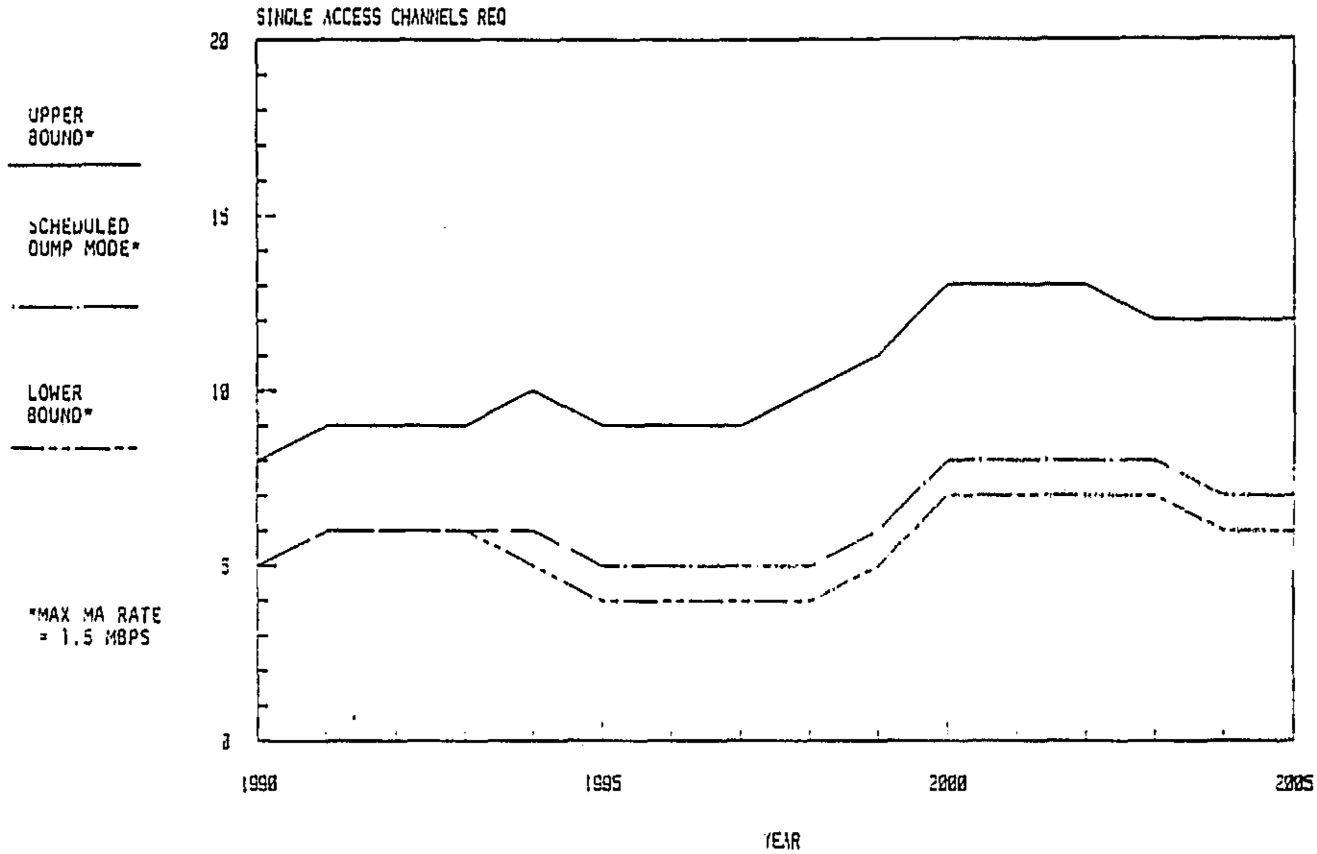
FIGURE 2.3-4

TDAS RETURN LINK CHANNELS (SA, MA) REQUIRED - SCENARIO A1



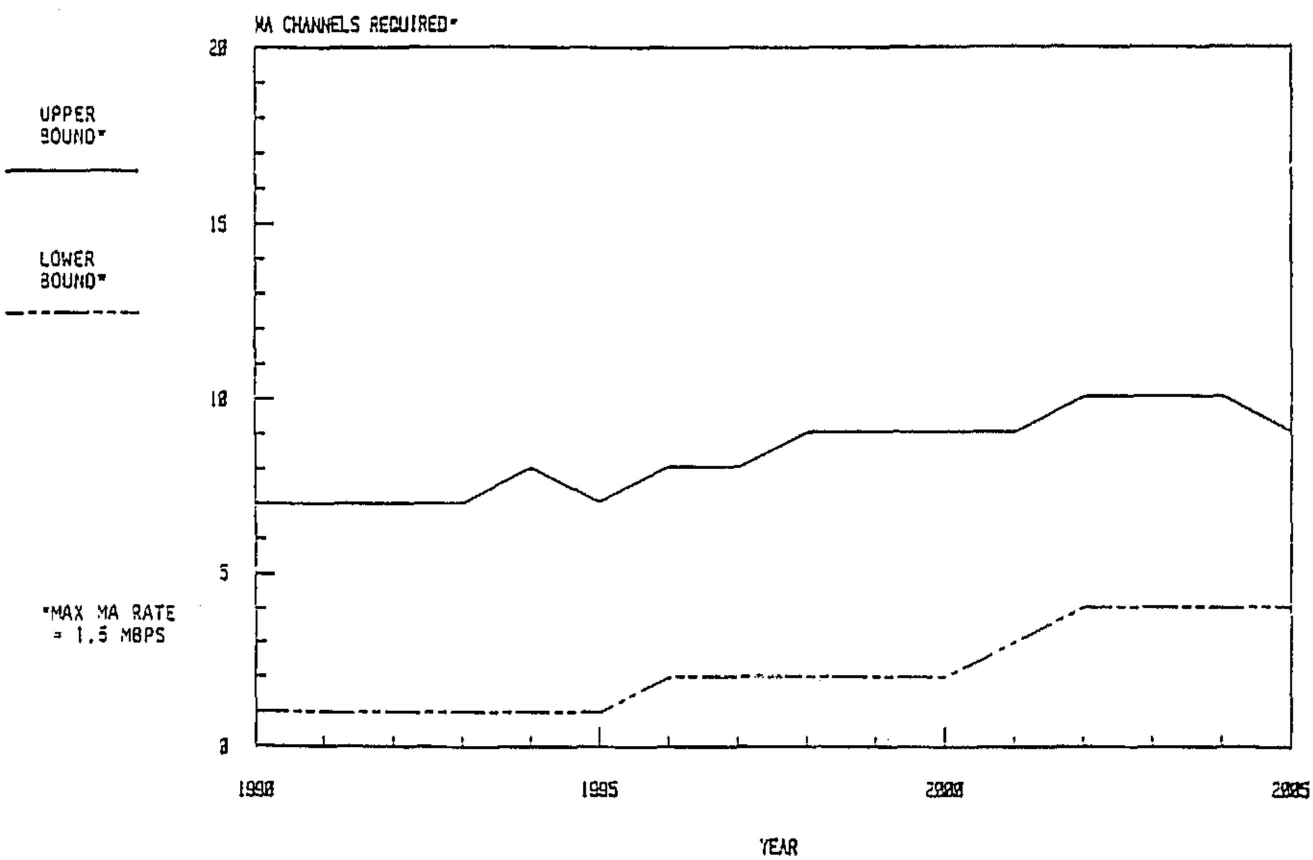
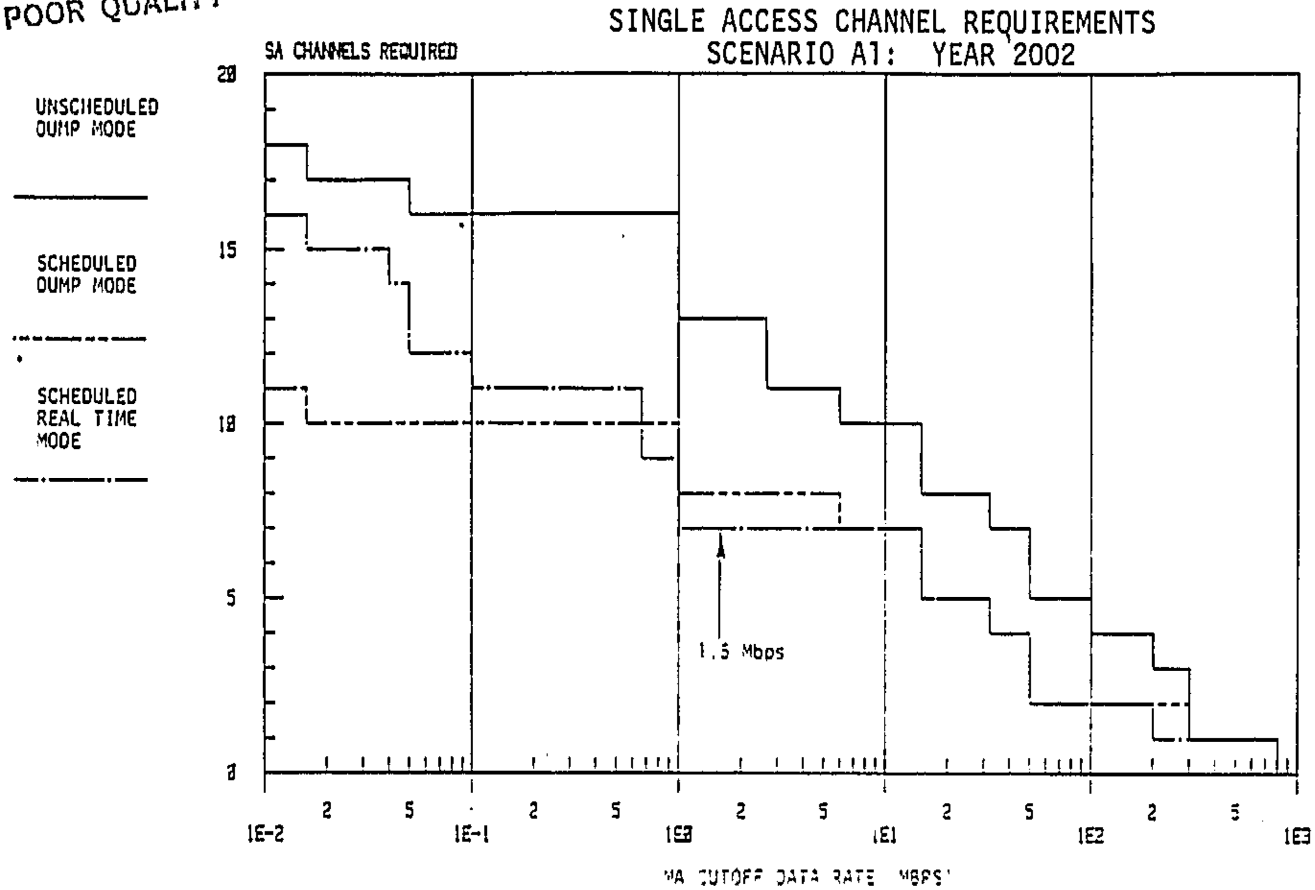
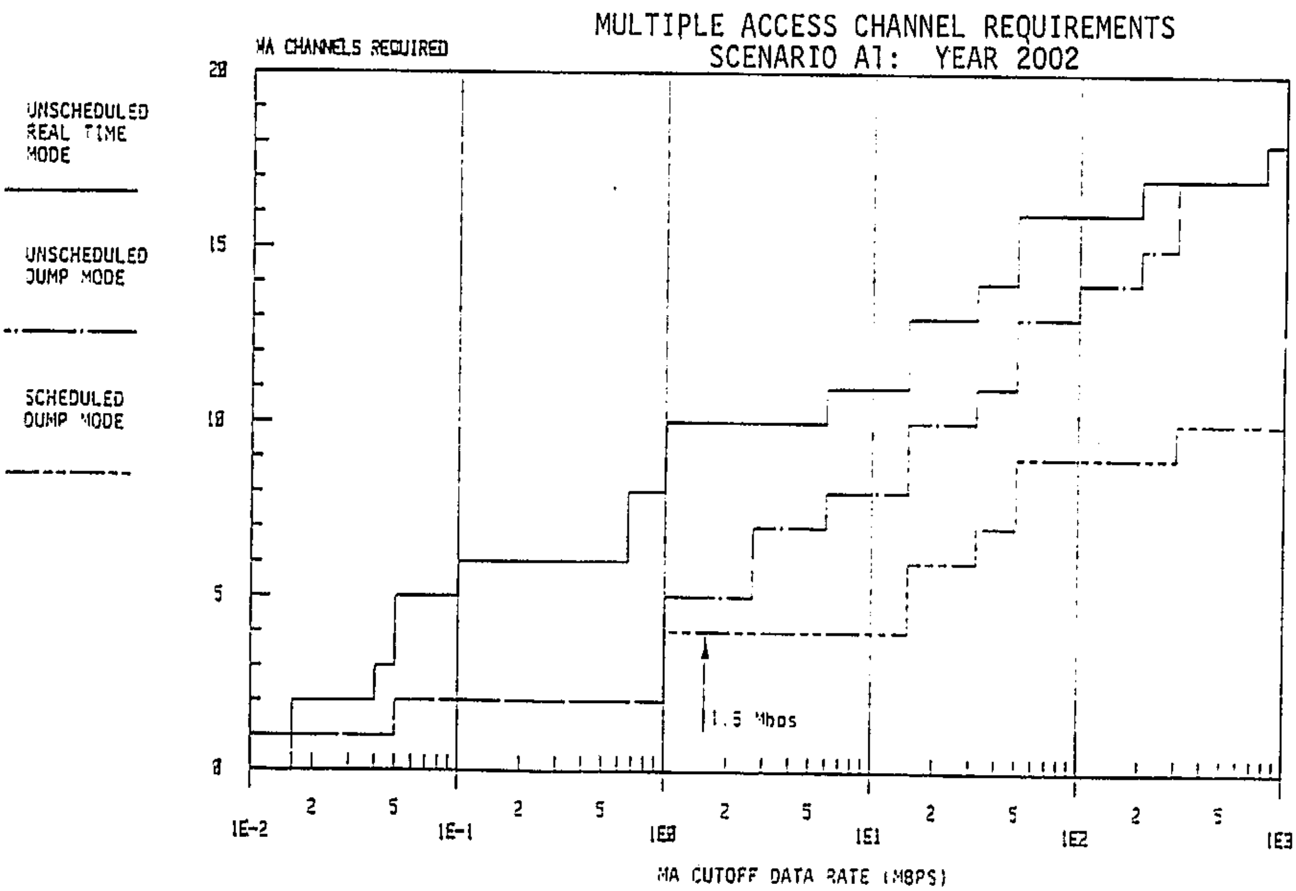


FIGURE 2.3-5: TDAS SA & MA CHANNEL REQUIREMENTS VS MA CUTOFF DATA RATE (SCENARIO A1)





demand with just three SA antennas per TDAS (still assuming a three satellite constellation). On the other hand, the MA cutoff data rate would have to increase by an order of magnitude in order to offer the possibility of supporting user demand with 2 SA antennas per TDAS. It, therefore, appears that the baseline assumption of a 1.5 Mbps cutoff data rate is a reasonable first-cut for the baseline model, subject to possible modification by later tasks.

All forward link data rates are $\leq$ 300 kbps and thus supportable by the MA service. However, any users already served by an SA return link antenna, are assumed to also use the same antenna for a forward link, thereby reducing the maximum MA load. This implies that SA forward link channelization is determined by SA return link channelization and furthermore has no impact on space segment antenna multiplicity.

With respect to MA service a preliminary analysis indicates that a total of 7 forward link MA channels per constellation would support average forward link MA demand (based on Scenario A1, at plan year 2002). For a 3 satellite constellation this is $\approx$ 3 forward link MA channels per TDAS. Since forward link usage is characterized by many short accesses (typically 10 minutes per access), scheduling should keep peak demand from significantly exceeding the average. This preliminary model assumes a maximum of 3 simultaneous forward links per TDAS. The possible impact on forward link MA self-interference will be investigated, if required in Task 5.

2.3.3 Communication Model Parameters

The TDAS Communication Model was set up to include two basic interrelated elements:

- A Frequency Plan (for each TDAS architectural option considered) that specifies center frequencies and bandwidths for each channel type.

- Link Budgets that validate transmit EIRPs, antenna G/T's and other link parameters based on required data rates and BER performance constraints.

These model elements will serve as the point of departure for the iterative tradeoff studies to be conducted in later tasks.

For this model four TDAS architectural options were assumed. They are distinguished by the nature of the space segment elements and/or the space/ground interface as defined below:

TDAS Architectural Option	Satellite Constellation Elements	TDAS Space/Ground Link		
		with TDAS CC	with Mission CC	with End Users
I	3-4 New S/C	Yes	No	No
II	"	"	Yes	"
III	"	"	"	Yes
IV	1 New S/C + 2-3 TDRS S/C	"	No	No

2.3.3.1 Frequency Plans. From a generic perspective two frequency plans were selected to support the TDAS options as noted in Figure 2.3-6. For the baseline model Frequency Plan A relies heavily on Q band for space-space links and K_a for earth-space links. Frequency Plan B is based largely on the TDRSS K_u band region. Details of each plan were developed in Task 10.

2.3.3.2 Link Budgets. Representative link budgets were developed to demonstrate performance in all four TDAS architectural options. They are a baseline set and will be revised in accordance with the results of later tasks. To illustrate one of the more difficult cases, budgets are presented for a return link service with crosslink connectivity as depicted in Figure 2.3-7. Non-crosslink service would yield higher system margins--in some cases significantly higher.

FIGURE 2.3-6

TDAS GENERIC FREQUENCY PLANS

ARCHITECTURAL OPTIONS		GENERIC DESCRIPTION OF FREQUENCY PLAN
Options I, II, III • 1990's technology • 23 satellites • Multiple Earth Stations for options II and III	⟷ TDAS TASK 10 ⟷	**Plan A** • Space-Space links on Q-band or light • Earth-Space links at K_a-band • Emergency Command linker at S-band
Option IV • Upgraded TDRSS constellation • At most 1 TDAS satellite • Downlink to White Sands only	⟷ TDAS TASK 10 ⟷	**Plan B** • TDRSS frequency plan augmented with Plan A for the transitional TDAS satellite

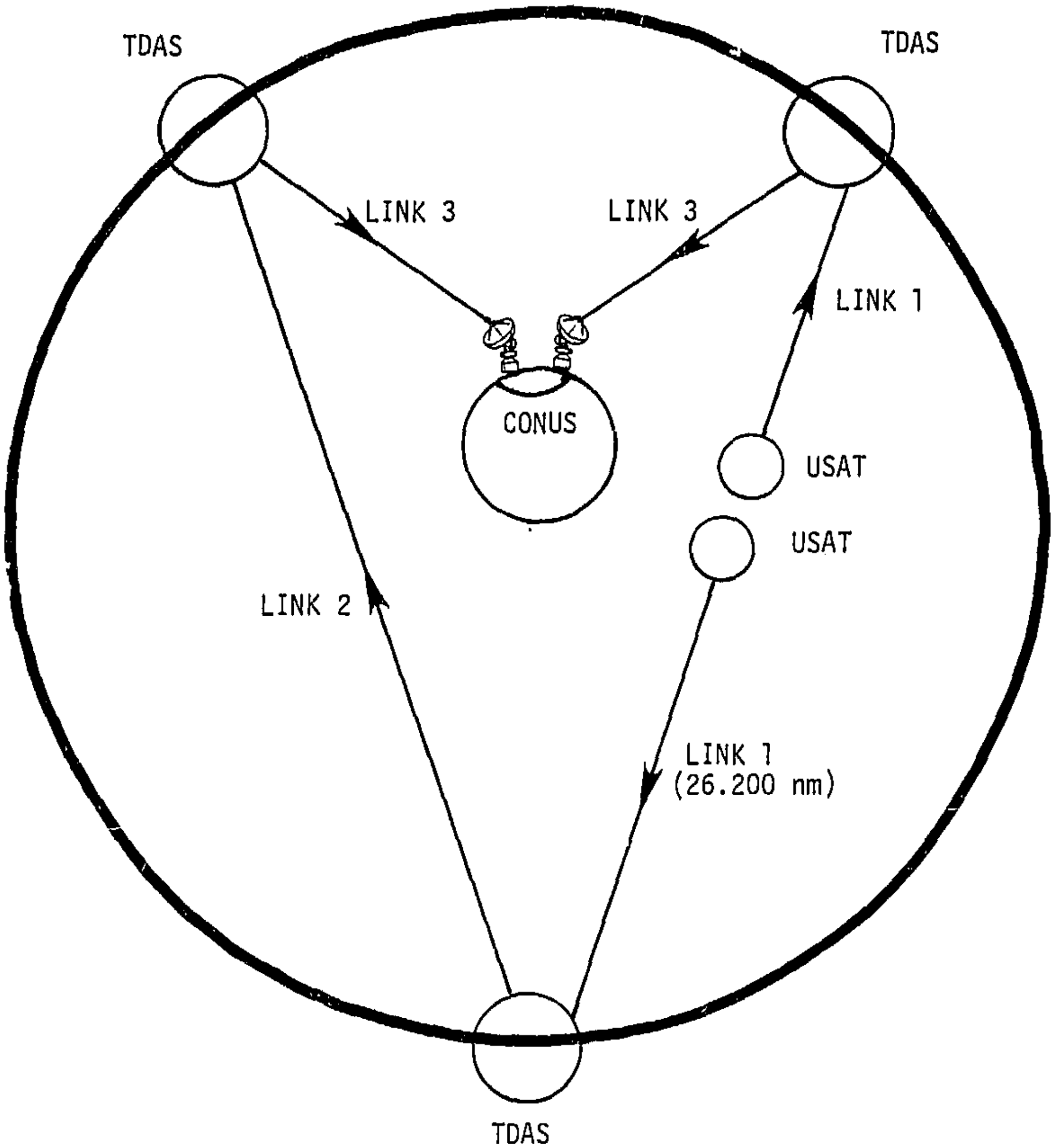


FIGURE 2.3-7
TDAS GEOMETRY FOR LINK BUDGET ANALYSIS

To evaluate combined link performance based on P/N_o for each of the three links in the system (USAT to TDAS, TDAS to TDAS, and TDAS to ground), the following approximation was employed

$$\frac{C}{N_o}_{\text{effective}} \cong \frac{(P/N_o)_1 \ (P/N_o)_2 \ (P/N_o)_3}{(P/N_o)_1 \ (P/N_o)_2 + (P/N_o)_2 \ (P/N_o)_3 + (P/N_o)_1 \ (P/N_o)_3}$$

where $(P/N_o)_i$ denotes the received power to noise spectral density ratio on the ith link, and C/N_o effective denotes the equivalent carrier-to-noise density ratio available at the ground receiver.

Budgets for SA and MA service are listed in Tables 2.3-3 and 2.3-4. These assume 10^{-5} BER performance, a Q-band crosslink, and the highest data rate for the service considered (1 Gbps for SA, 1.5 Mbps for MA).

Note that with the baseline assumption of a 50 Watt Q-band crosslink, the first and second links contribute about equally to system noise. The user spacecraft must compensate for crosslink noise and, therefore, TDAS crosslinking is not transparent to user operations.

2.3.3.3 Parametric Link Quality Analyses. Parametric analyses were made between space-space and space-earth link qualities to illustrate possible trades which depart from baseline model parameters, but maintain a specified system performance (e.g. BER). As an example, Figure 2.3-8 shows the link quality relationships between pairs of links in the three segment SA return link considered in the previous subsection.

The tradeoffs are made with respect to the quality of individual links, where

Quality = (TRANSMIT EIRP) + (RECIEVE G/T)

All values are expressed in dB. The link quality expresses those channel parameters available to manipulation by the system designer.

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TABLE 2.3-3

Q-BAND SA RETURN LINK BUDGETS
(1 Gbps USER/WHITE SANDS TERMINAL)

	1ST LINK	2ND LINK	3RD LINK
NOTES			
Frequency in GHz	60	60	20
XMT Antenna Dia (ft)	6	8	8
RCV Antenna Dia (ft)	8	8	60
XMT Antenna Efficiency	0.7	0.7	0.55
RCV Antenna Efficiency	0.7	0.7	0.65
Link Distance (nmi)	26200	42800	21700
Data Rate (mbps)	1000	-	-
Modulation Technique	QPSK	-	-
Bandwidth (MHz)	1000	-	-
Coding	No	-	-
BUDGET			
Transmitter Power (DBW)	16.0	17.0	17.0
Line Loss	-2.7	-3.8	-3.0
XMT Antenna Gain	59.7	62.2	51.6
Pointing Loss	-0.5	-0.5	-1.0
Net EIRP (dBw)	72.5	75.9	67.6
Space Loss	-221.7	-226.2	-210.3
Rain Loss	-	-	-3.7*
Atmospheric Loss	-	-	-1.0
RCV Antenna Gain	62.2	62.2	69.8
Pointing Loss	-0.5	-0.5	-0.5
Line Loss	-3.3	-3.3	-1.5
System Noise Temp.	-27.9	-27.9	-26.6
Receive G/T	30.5	30.5	35.2
Receive P/N_o (dB-Hz)	109.9	108.8	119.4

COMBINED LINKS	Total Paths
Combined C/kT (dB-Hz)	106.1
Data Rate (dB + bps)	90.0
E_b/N_o into Combiner	16.1
Theoretical Combiner Gain (dB)	-
CAL and COMB losses	-
Pointing loss	-
E_b/N_o into Demodulator (dB)	16.1
Demodulator loss	3.0
E_b/N_o Available	12.8
E_b/N_o Required (BER = 10^{-5})	9.6
System Margin	3.5

* Assumes Ground terminal antenna diversity and 99.99% availability.

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TABLE 2.3-4

Q-BAND MA RETURN LINK BUDGETS

(1.5 Mbps USER/WHITE SANDS TERMINAL)

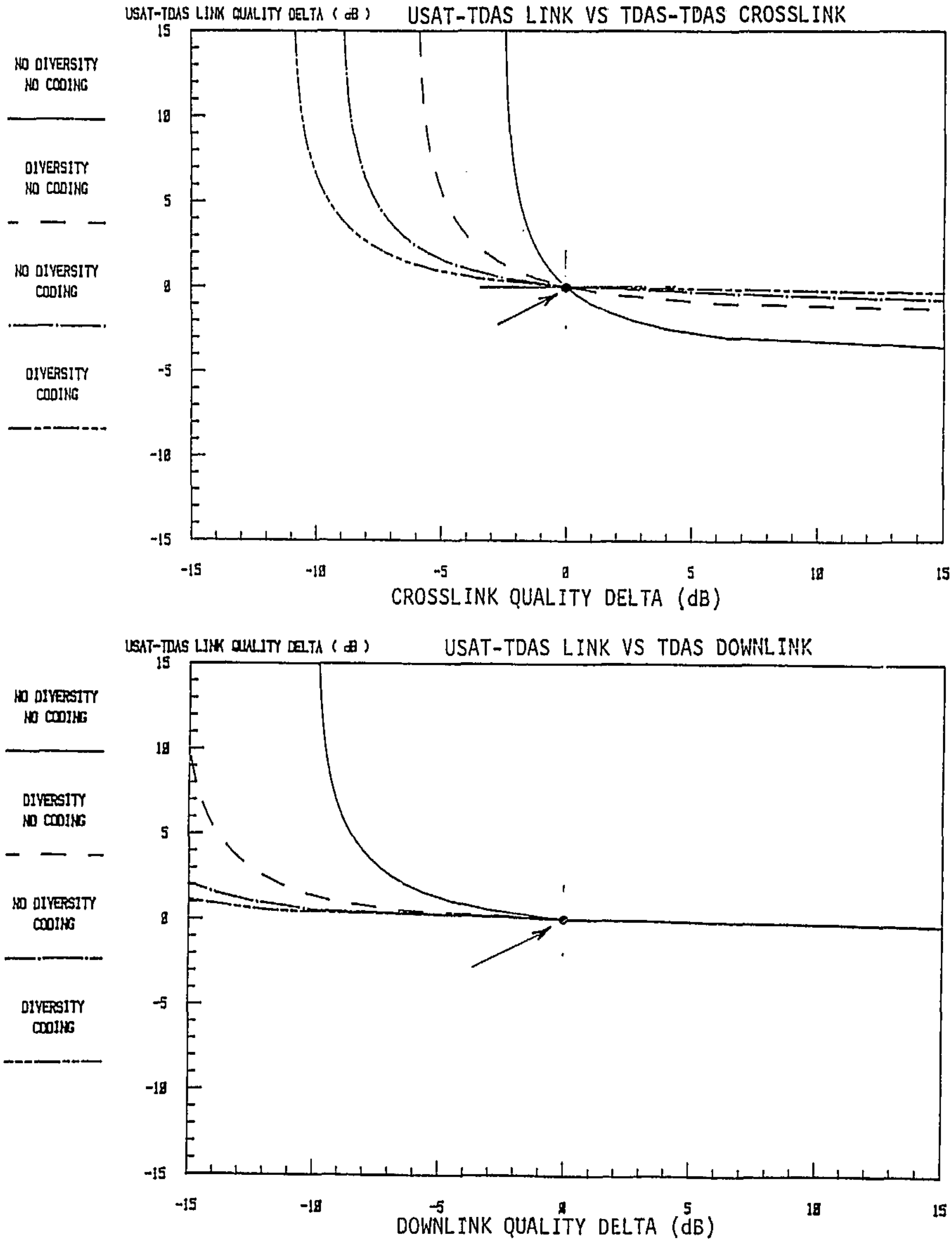
	1ST LINK	2ND LINK	3RD LINK
NOTES			
Frequency in GHz	60	60	20
XMT Antenna Dia (ft)	6	8	8
RCV Antenna Dia (ft)	-	8	60
XMT Antenna Efficiency	0.7	0.7	0.55
RCV Antenna Efficiency	0.6	0.7	0.65
Link Distance (nmi)	26200	42800	21700
Data Rate (Mbps)	1.5	-	-
Modulation Technique	QPSK/PN	-	-
Bandwidth (MHz)	45	-	-
Coding	No	-	-
BUDGET			
Transmitter Power (DBW)	17.0	-10.0	-20.0
Line Loss	-2.7	-3.8	-3.0
XMT Antenna Gain	59.7	62.2	51.6
Pointing Loss	-0.5	-0.5	-1.0
Net EIRP	73.5	47.9	40.6
Space Loss	-221.7	-226.2	-210.3
Rain Loss	-	-	3.7*
Atmospheric Loss	-	-	-1.0
RCV Antenna Gain	13.0	62.2	69.8
Pointing Loss	-	-0.5	-0.5
Line Loss	-3.3	-3.3	-1.5
System Noise Temp.	-27.9	-27.9	-26.6
Receive G/T	-18.2	30.5	35.2
Receive P/N_o (dB-Hz)	62.2	81.8	82.4

	Total Paths
COMBINED LINKS	
Combined C/kT (dB-Hz)	62.1
Data Rate (dB + bps)	-61.8
E_b/No into Combiner (dB)	0.3
Theoretical Combiner Gain (dB)	14.4
CAL and COMB losses	-1.3
Pointing Loss	-0.1
E_b/N_o into Demodulator (dB)	13.3
Demodulator Loss	3.6
E_b/N_o Available	9.7
E_b/N_o Required	9.6
System Margin	0.1

* One inchips MA self-interleaving

FIGURE 2.3-8

DELTA LINK QUALITY RELATIONSHIPS FOR TDAS
SA RETURN LINK (ARCHITECTURE OPTION I)



These graphs are a pictorial guide to the relationship between various links in the communication system. As an example, consider the case of a Q-band single access link without user coding but with antenna diversity at White Sands. If one wishes to reduce crosslink quality by 5 dB, what increase in USAT-TDAS link quality is required to maintain performance? The upper chart indicates an increase of ≈ 6 dB is required to maintain performance. On the other hand, an increase of 1 dB would be sufficient with the use of rate 1/2 coding (constraint length 7). The USAT-TDAS link can be traded against the downlink in a similar manner. The lower chart in Figure 2.3-8 illustrates the significant downlink degradation supportable with minimal USAF-TDAS link strengthening. This is a direct consequence of the relatively strong (ie, noise-free) downlink assumed in the baseline architectures.

2.4 TASK 4 - USER GROUND DATA SYSTEM ARCHITECTURE

Task 4, User Ground Data System Architecture, is concerned with generation and modelling the user ground data system requirements. The user ground segment options will be developed along with cost estimating data for use in the overall TDAS cost estimates. Finally, the user ground segment portion of the performance assessment simulation will be developed.

Work on Task 4 started in the later portion of the reporting period. Detailed planning and definition of the required effort has been accomplished. Figure 2.4-1 illustrates the results of this planning effort. The present effort is concentrated on determining the user ground segment requirements and investigating the impact of end-to-end data system programs on the user ground segment.

The user ground segment requirements are being determined by identifying the science data users through the point where the data is archived; identifying the payload operations control center and its assigned functions; reviewing the planned data flow; and reviewing the plans for packetizing. This information will also be used to synthesize the architecture for generic user ground segments including both single-mission spacecraft and space platforms.

Concurrent with the above effort, the various end-to-end data system programs are being investigated in order to determine their impact on the user ground segment. In particular, NEEDS, ADS, Data System 90 and EEIS have been identified as potentially impacting the ground segment. For these programs, existing literature is being reviewed and discussion held with NASA personnel.

2.5 TASK 5 - TDAS SYSTEM ARCHITECTURE AND SUBTASK 5A - TDAS RETRIEVAL

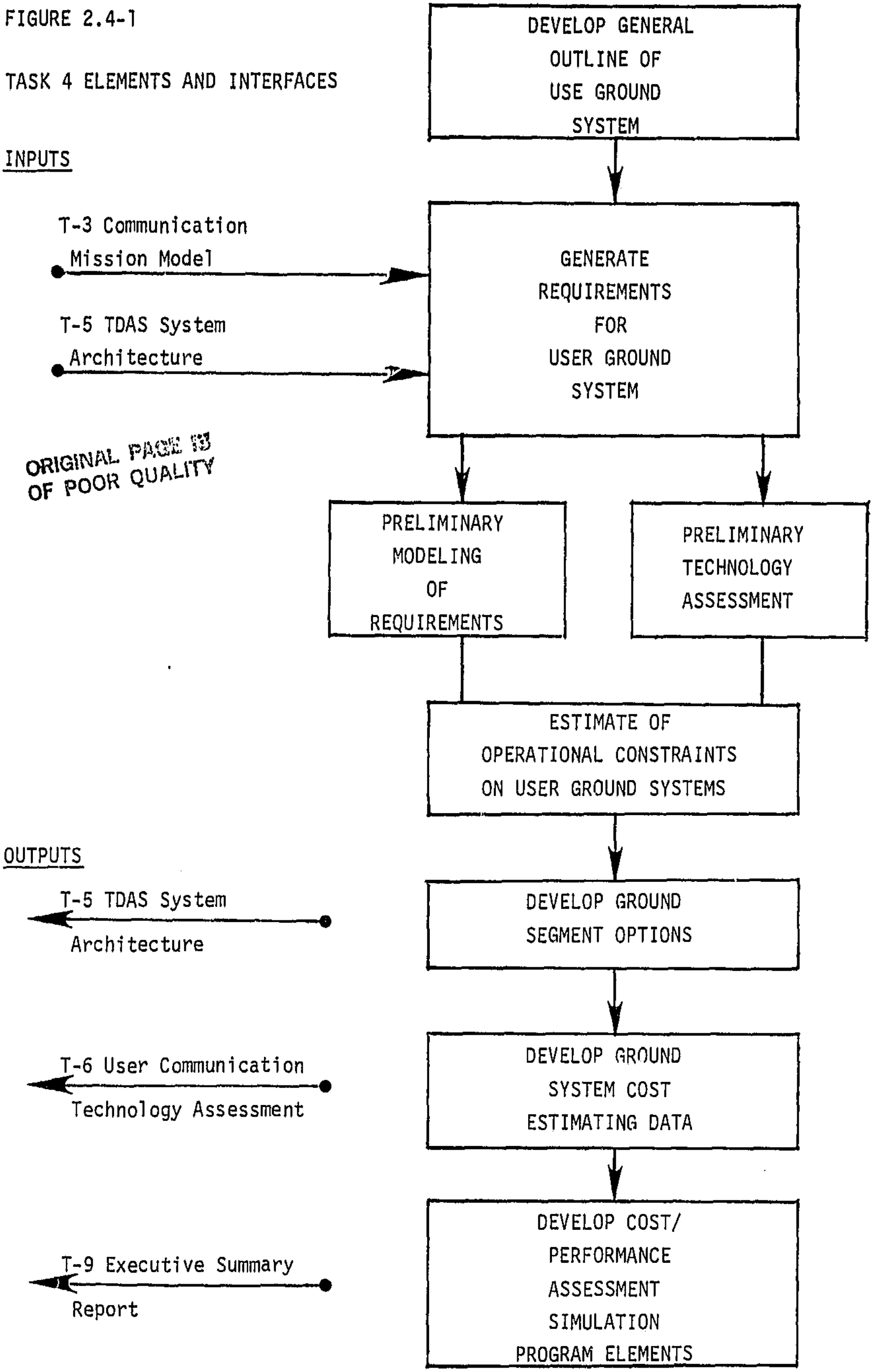
This task is scheduled to start in November.

2.6 TASK 6 - USER COMMUNICATION TECHNOLOGY ASSESSMENT

This task is schedule to start in April, 1982.

FIGURE 2.4-1

TASK 4 ELEMENTS AND INTERFACES



2.7 TASK 7 - TDAS COMMUNICATIONS TECHNOLOGY ASSESSMENT

This task is scheduled to start in April, 1982.

2.8 TASK 8 - OPERATIONAL ASPECTS

This task is scheduled to start in February, 1982.

2.9 TASK 9 - EXECUTIVE SUMMARY REPORT

This task is scheduled to start in February, 1983.

2.10 TASK 10 - FREQUENCY PLAN AND RADIO FREQUENCY INTERFERENCE MODEL DEVELOPMENT AND SUBTASK 10A - FREQUENCY MANAGEMENT

Task 10 is reported in Paragraph 2.10.1 and Subtask 10A in Paragraph 2.10.2.

2.10.1 Frequency Plan and RFI Model Development

Figure 2.10-1 shows the structure of Task 10, based on the following items:

Define a TDAS frequency utilization plan for each configuration studied consistent with the 1984 WARC. In addition, for each frequency band considered, define a radio frequency interference (RFI) model which will take into consideration classified as well as unclassified data bases. Based on this model, the next step is to define for each system and/or signal structure, the survivability of the system to this environment. In addition, requirements are to be developed which will provide robust operation in this environment.

Summary of Progress to Date

During the reporting period, two strawman frequency utilization plans were developed for the architectural options under study. Plan A supports options 1-3, involving the next generation TDAS space segment. Plan B is a duplication of current TDRSS frequency utilization, consistent with architectural option 1 (TDRSS-upgraded constellation). With respect to Plan A, certain TDRSS bands may be retained for space-to-space links to provide a transitional capability. The selection of a transition band(s) has not been finalized .

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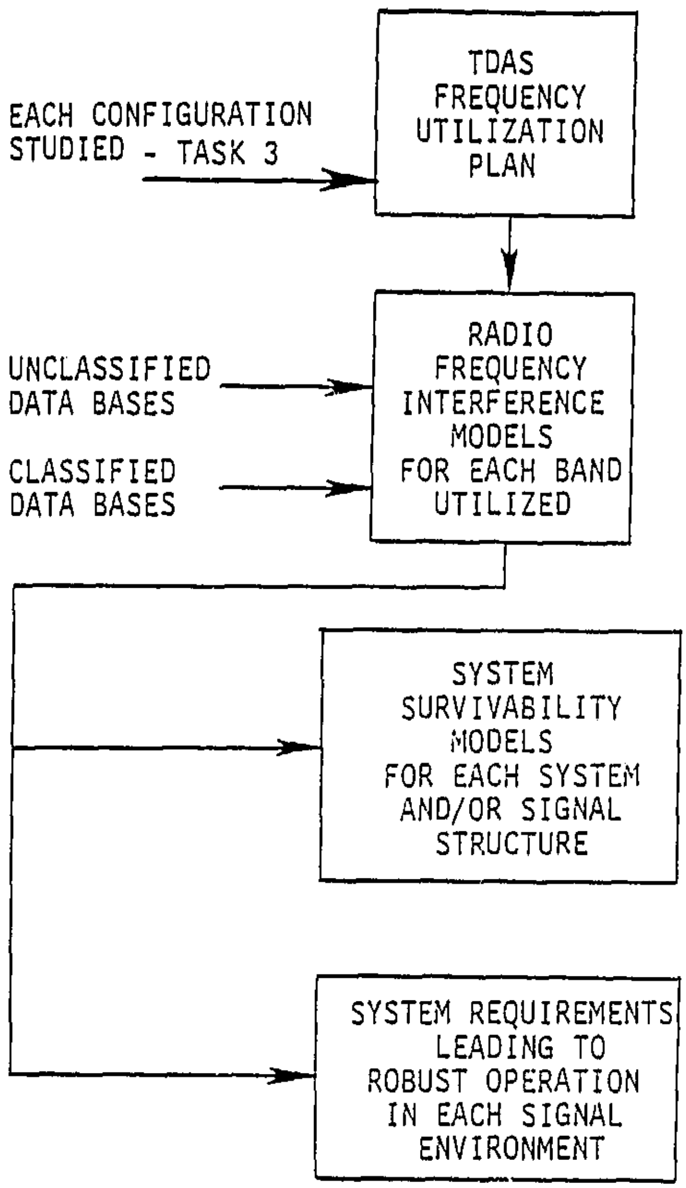
FIGURE 2.10-1

TASK 10 ELEMENTS AND INTERFACES



Plans A and B will be defined so as to meet the needs of the projected user community, with respect to bandwidth and data rate requirements (as defined in Tasks 1 and 2). Further analysis is necessary, including consideration of the RFI model results, to arrive at a final TDAS Frequency plan under this task.

In addition, work was performed on RFI model development for the candidate TDAS frequency bands, through review and analysis of TDRSS and SCS data sources. The RFI model is not yet complete.

A small amount of work was done in the two remaining areas:

- Survivability Models
- Requirements for Robust Operation

This work consisted of very preliminary problems analyses. There are no reportable results at this time.

2.10.5 Subtask 10A - Frequency Management

This subtask is planned to be active intermittently, over the life of this contract. It requires liaison with NASA frequency managers and groups charged with coordinating and managing the assignment and use of frequency bands for NASA, together with development, coordination and presentation of plans and requirements for the TDAS frequency utilization in support of the 1984 (85) WARC. The subtask elements and interfaces are as shown in Figure 2.10-2.

To date, there have been no frequency planning meetings scheduled. The task activities have included some liaison meetings with NASA planners, and review of frequency assignment relative to the previous (1979) WARC.

Summary of Progress to Date

The decisions/recommendations of the 1979 World Administrative Radio Conference (WARC-79) are currently being reviewed in order to assess their potential impact on the TDAS architecture. Addtionally, the planning for the 1985 WARC on space services is being reviewed for potential impact on TDAS.

The literature survey was continued and coordination with NASA on the frequency management issues for TDAS was initiated.

2.11 TASK 11 - THREAT MODEL DEVELOPMENT/SECURITY ANALYSTS

This task is concerned with developing a TDAS Threat Model and via its use assuring the security of the command and data links of the TDAS. Requirements for secure operation shall, as a result, be developed.

2.11.1 Threat Model Development

The initial effort on this task was to identify the particular links and possible frequencies for which model development will be accomplished.

These are (i) the ground-to-space links for command and control (15 or 30 GH_z), (ii) the space-to-ground links for return data and telemetry (14 or 20 GHz), (iii) the crosslinks (laser or 60 GHz), (iv) the TDAS-to-user links (2,15 or 60 GHz), and (v) the user-to-TDAS links (2, 15 or 60 GHz). Future work on Task 10 may narrow the frequency options to be studied.

To begin the study, material developed under a comparable effort was reviewed. This was the Satellite Control Satellite (SCS)* study performed by Stanford Telecommunications, Inc. and Ford Aerospace. In this study all the links identified above were investigated for jam resistance, but not all frequencies potentially considered for TDAS were taken into account. The findings, which will be used to guide the TDAS Threat Model development, are summarized below. The following notation is used:

MS = Mission Satellite (User)
SCS = Satellite Control Satellite (Relay)
GND = Ground Station

The link from A to B is denoted A/B.

---

* A.k.a. SCDRS (Satellite Control and Data Relay System) at its inception.

- <u>MS/SCS</u> - Not jammable at O_2 absorption frequencies (W-band, 60 GHz). For wideband links (> 1 Gbps), absorption is less across the band, and may be susceptible. Suggests bandwidth efficient modulation should be used at high rates. Short (< 5 min) periods of vulnerability due to geometry can be eliminated by using 2 SCS's.

- <u>SCS/SCS</u> - Not jammable at W-band due to O_2 absorption + antenna discrimination for data rate < 1 Gbps.

- <u>SCS/GND</u> - Analyzed at 15 and 40 GHz. Results for 20 GHz expected to be similar. Need sidelobe cancelling or screening against worst case airborne threat.

- <u>GND/SCS</u> - Analyzed at 14 and 40 GHz. Results for 30 GHz expected to be similar. For commands (60 Kbps) can get 30 dB processing gain. Jammer exclusion from mainbeam better at 40 GHz (for fixed antenna size at SCS). May conclude that 30 GHz is fairly good, too. Don't need antenna discrimination beyond keeping jammer out of 3dB mainlobe.

  Options: Off-pointing, null-steering

- <u>SCS/MS</u> - Analyzed at 60 GHz. No Spread Spectrum required, but sum of atmospheric plus antenna discrimination claimed to be

>120 dB. This is a large number that should be checked against, for example, the SCS/SCS case.

2.11.2 Security Analysis

No work has been started on the Security Analysis part of the task.

2.12 TASK 12 - UPGRADING THE SAMSO COST MODEL

This task is concerned with modifying the SAMSO Unmanned Spacecraft Cost Model (USCM) where necessary to reflect NASA's satellite program cost experience. Cost predictions derived by both SAMSO and GSFC cost models will be compared with actual costs for several recent NASA programs. The results will be used to reformulate certain Cost Estimating Relationships (CERs) for use in generating satellite cost predictions needed in TDAS study Tasks 2, 5 and 14. Figure 2.12-1 shows Task 12 elements and interfaces.

2.12.1 Review of Cost Model Documentation

Two models for the prediction of satellite costs have been developed to assist in the planning of alternative systems at both the preliminary definition level and subsequent design stages. This section summarizes the pertinent SAMSO and GSFC Cost model elements which will be compared.

2.12.1.1 The "SAMSO" Model*.

An extensive effort by the Cost Analysis Division at the USAF Space Division (formerly SAMSO) has produced a model for estimating the costs of unmanned satellite systems. It is based on a parametric estimation approach wherein historical cost data for several spacecraft programs were correlated with respect to various physical and performance characteristics of those systems to identify the key parameters or "cost drivers." The data base utilized in developing the model has been continually updated and as of 1981 included 35 systems representing over 135 satellites. As indicated in Table 2.12-1, these include a range of applications: military, weather, experimental, communications, and a lunar probe.

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* "Unmanned Spacecraft Cost Model," (5th Edition) Space Division, SD-TR-81-45, June 1981.

FIGURE 2.12-1
TASK 12 ELEMENTS & INTERFACES

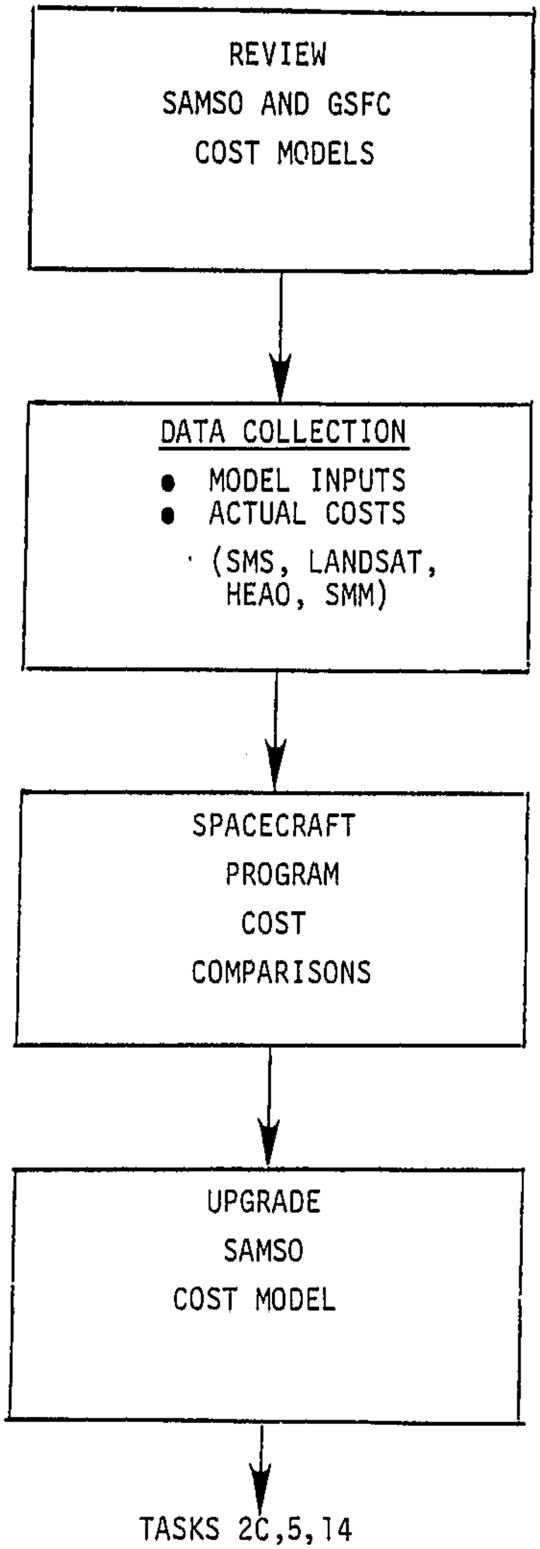

TABLE 2.12-1

SATELLITE PROGRAMS IN COST MODEL DATA BASE

PROGRAM SPONSOR	SAMSO MODEL (1981)	GSFC MODEL (1980)
NASA	SYNCOM LUNAR ORBITER ATS A (M/G) ATS B,C (S/S) ATS D,E (S/G) TIROS M NIMBUS E,F ERTS A,B SMS OSO I ATS F AE HEAO	TIROS M ERTS A,B SMS OSO I ATS F HEAO
AIR FORCE	VELA VASP IDCSP IDCSP/A TACSAT DSP I DSCS II DSP II P72-2 S3 NATO II P78-1 P78-2 GPS-1 FLTSAT DMSP (5D)	IDCSP/A TACSAT DSCS II
COMMERCIAL	INTEL III INTEL IV MARISAT	INTEL III

While the applications may differ, many similar functions are required in all types of spacecraft, e.g., electrical power, thermal control, structure, etc. By observing several satellite programs, Cost Estimating Relationships (CERs) were formulated for the total satellite platform or appropriate subsystems as a function of pertinent parameters (e.g., weight, solar array output, etc.). CERs are available for both non-recurring (NR) and first unit (FU) hardware costs. Learning curve effects can also be introduced as a function of the number of satellites involved. In addition to the hardware costs, other elements typically included in the overall estimates are program level costs, contractor fees and certain miscellaneous items, such as launch and orbital operations support (LOOS), and aerospace ground equipment (AGE) costs.

For programs beyond the system definition phase the model can be used for detailed estimates on a subsystem by subsystem basis utilizing, if desired, various complexity and technology carry-over factors to develop a composite estimate. When only gross estimates are of interest, the regular (unnormalized) CERs can be used along with known standard deviations of the model error to compute high, average and low estimates. The latter approach is to be followed in this task.

NR and FU cost elements defined by CERs in the SAMSO model are listed in Table 2.12-2. Note that no costs for the spacecraft payload (experiments) are included, since these are mission specific. CERs for program level, AGE and LOOS costs were derived after subtracting all payload related costs. Discussion of specific CERs is deferred to Section 2.12-2.

2.12.1.2 <u>The GSFC Model</u>*. Under direction of the Resource Analysis Group (RAG) at GSFC, a model to derive cost estimates for future free flyer spacecraft was developed. It was based on ten systems for which adequate historical documentation, cost, technical and programmatic data, representative of GSFC programs, was available. As indicated in Table 2.12-1, these systems are also included in the SAMSO model data base.

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* "Interim GSFC Free Flyer Spacecraft Cost Model," PRC System Services Co., Huntsville, Alabama, June 1980.

TABLE 2.12-2

SAMSO SPACECRAFT COST MODEL

ELEMENTS	NON-RECURRING COSTS	FLIGHT UNITS COSTS
SPACECRAFT SUBSYSTEMS		
• STRUCTURE/THERMAL CONTROL & INTERSTAGE	X	X
• ELECTRICAL POWER	X	X
• COMMUNICATIONS	X	X
• TELEMETRY, TRACKING & COMMAND	X	X
• ATTITUDE CONTROL	X	X
• PROPULSION	X	X
FLIGHT HARDWARE (E.G., EXPERIMENT) PAYLOAD		
DISPENSER	X	X
PROGRAM LEVEL (NOT SUBSYSTEM PECULIAR)	X	X
PROGRAM MANAGEMENT SYSTEMS ENGINEERING SYSTEMS TEST & EVALUATION ACCEPTANCE TEST DATA MANAGEMENT		
AEROSPACE GROUND EQUIPMENT (AGE)	X	-
LAUNCH & ORBITAL OPERATIONS SUPPORT (LOOS)	-	X

CERs are provided for estimating protoflight (PF) and flight unit (Flt U) costs by major subsystem for the spacecraft bus (no payload). A wraparound cost factor is a percentage multiplier applied to aggregate subsystem costs to estimate system level costs. These account for assembling the subsystems into an overall spacecraft, testing, systems engineering, integration, program management and other support functions. PF and Flt U cost elements defined by CERs in the GSFC model are listed in Table 2.12-3.

2.12.2 Cost Model Input Data Collection

Differences in using the models arise in two ways. One is the subsystem CER input data requirements and the other involves interpretation of the cost estimates once the CERs are evaluated (NR and FU costs vs PF and Flt U costs). The latter will be resolved in the next reporting period.

With respect to CER inputs the GSFC model requires only total subsystem weights for 5 major subsystems. The SAMSO model requires weights for some and different parameter for others. A list of the model CERs and input parameters requirements is given in Table 2.12-4.

Four satellite systems in various weight classes were selected for cost comparison.

- SMS-1 (low weight, spin stabilized)
- Landsat-1,2,3 (medium weight, 3 axis stabilized)
- HEAO-2,3 (higher weight, 3 axis stabilized)
- SMM (MMS configuration, 3 axis stabilized)

Collection of data subsystem weights, solar array power, and other parameters) needed to set up inputs to the models was completed.

The next step is proceeding: evaluation of spacecraft system costs via each model and comparison with actual costs (payload and launch costs omitted).

TABLE 2.12-3

GSFC SPACECRAFT COST MODEL

ELEMENTS	PROTO FLIGHT UNIT COSTS	FLIGHT UNIT COSTS
SPACECRAFT SUBSYSTEMS		
• STRUCTURE/THERMAL CONTROL	X	X
• ELECTRICAL POWER	X	X
• COMMUNICATIONS, COMMAND & CONTROL	X	X
• ATTITUDE DETERMINATION & CONTROL	X	X
• REACTION CONTROL/PROPULSION	X	X
INSTRUMENTS (PAYLOAD)		
WRAPAROUND (MSI&T)	X	X
PROJECT MANAGEMENT SYSTEMS ENGINEERING PRODUCT ASSURANCE SYSTEMS TEST OPERATIONS ASSEMBLY & INTEGRATION GROUND SUPPORT EQUIPMENT SYSTEM HARDWARE		
LAUNCH & ORBITAL OPERATIONS SUPPORT		

TABLE 2.12-4

COST MODEL CERs

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SAMSO MODEL

SUBSYSTEMS	NONRECURRING CER (1979\$ x 10^3)	FIRST UNIT CER (1979\$ x 10^3)	INPUT PARAMETER
Structure, TC & Interstage	$C = 1203.97 + 112.93W^{.66}$	$C = 23.64W^{.65}$	Subsystem Weight (lbs)
TT&C	$C = 892.08 + 41.18W$	$C = 42.43 + 35.93W^{.93}$	TT&C Weight (lbs)
Communications	$C = 564.68W^{.56}$	$C = 49.96W^{.87}$	COMM Weight (lbs)
Combined COMM & TT&C	$C = 3188.33 + 195.86W^{.74}$	$C = 48.30W^{.89}$	Combined COMM & TT&C Weight(lbs)
Attitude Determination	$C = 1886.01 + 144.58W$	$C = 37.24W$	AD Dry Weight (lbs)
Attitude & Reaction Control	$C = 426.49 + 31.47W$	$C = 166.12 + 47.87W^{.73}$	A&RC Dry Weight (lbs)
Total Attitude Control Subsystem	$C = 960.72 + 75.54W$	$C = 29.08W^{.95}$	ACS Dry Weight (lbs)
Electrical Power Supply (EPS)			
• for Subsynchronous Altitude	$C = 360.97 + 0.165Y$	$C = 381.30 + .3345Y$	EPS Weight x BOL Power(lbs-watts)
• for Synchronous Altitude & Above	$C = 2419.43 + .02295Y^{.97}$	$C = 66.44Y$	EPS Weight x BOL Power(lbs-watts)
Apogee Kick Motor (AKM)			
• 1-Axis Stabilized	$C = 223.37 + .01075Z$	$C = 14.89Z^{.72}$	Total Impulse (lbs-sec)
• 3-Axis Stabilized	$C = .003235Z$	$C = .001057Z$	Total Impulse (lbs-sec)
Program Level Factor			
• for Communication Satellites	$C = 1.3568X$	$C = 1.3291X$	AGGREGATE Subsystem Cost
• for all Spacecraft	$C = 1.4640X$	$C = 1.4568X$	AGGREGATE Subsystem Cost
AGE Factor	$C = 1.1131X$	$C = 1.1131X$	AGGREGATE Subsystem Cost

GSFC MODEL

SUBSYSTEMS	PROTOFLIGHT UNIT CER (1979\$ x 10^3)	FLIGHT UNIT CER (1979\$ x 10^3)	INPUT PARAMETER
Structure/Thermal Control	$C = 448W^{.426}$	$C = 11.8W^{0.72}$	Subsystem Weight (lbs)
Communications, Command, and Data Handling	$C = 306W^{.766}$	$C = 51.9W^{0.84}$	" " "
Attitude Determination and Control	$C = 330W^{.693}$	$C = 54.3W^{0.79}$	" " "
Power Source, Storage, and Distribution			
• (Body-Mounted Array)	$C = 347W^{.578}$	$C = 40.1W^{0.64}$	" " "
• (Paddle-Mounted Array)	$C = 315W^{.453}$	$C = 40.1W^{.064}$	" " "
Reaction Control/Propulsion	$C = 147W^{.153}$	$C = 118.0W^{0.41}$	" " "
System Level Factor	$C = 1.6X$	$C = 1.6X$	AGGREGATE Subsystem Cost

2.13 TASK 13 - VITERBI DECODER/SIMULATOR STUDY

Paragraphs 2.13.1 through 2.13.7 cover Task 13. Task 13A reporting is presented in paragraph 2.13.8.

2.13.1 Introduction

The objective of this study is to evaluate the synchronization and tracking capabilities of Viterbi decoders in the presence of pulsed RFI under varying levels, repetition rates and duty cycles.

During the second three months, the duality of the software simulator with the hardware simulator was verified for error and synchronization performance. The Viterbi decoder performance for the Space Telescope RFI environment was tested, and the preliminary conclusion is that the decoder will not detect loss of synchronization erroneously. The software simulator has provided data on minimum metric growth and the inter arrival time of the SYNCLOSS signal (this signal from the decoder flags the deinterleaver that the minimum metric has been growing too fast). Further work on modeling the synchronization behavior on the basis of the metric growth is necessary. The last section describes the approach to evaluate the error propagation and metric growth as function of RFI pulse duration and intensity.

The interim report will be issued in January 1982, which gives the opportunity to include more details on the software package.

2.13.2 Verification of the Software Simulator

Table 2.13-1 shows the results of simulating a channel with one or two RFI sources on the hardware and software simulators. Only those channels which do not cause the simulator to generate a loss of synchronization signal could be used for comparison, because this signal causes the decoder in the hardware simulator to change its timing, which may cause additional errors.

CHANNEL DESCRIPTION	DUTY CYCLE	HOLD TIME	ERRORS/BIT	
			HARDWARE SIMULATION	SOFTWARE SIMULATION
AWGN,	.930	1	2.6×10^{-5}	$< 10^{-4}$ (0 ERRORS AFTER 3 10^{5} BIT SIMULATION)
NOISE RFI, 45 dBW EIRP	.070	1		
AWGN, E_b/N_o = 8.5 dB	.676	1	1.8×10^{-2}	1.4×10^{-2}
FINITE CW RFI, 40 dBW EIRP, IN BAND	.108	20		
FINITE CW RFI, 50 dBW EIRP, IN BAND	.216	20		
AWGN, E_b/N_o = 8.5 dB	.928	1	2.6×10^{-2}	2.5×10^{-2}
FINITE CW RFI, 50 dBW EIRP, IN BAND	.036	10		
INFINITE NOISE OR CW RFI, 100 dBW EIRP, OUT OF BAND	.036	10		
AWGN, E_b/N_o = 8.5 dB	.992	10	2.3×10^{-3}	2.4×10^{-3}
FINITE CW RFI, 50 dBW EIRP, IN BAND	.004	10		
INFINITE NOISE OR CW RFI, 100 dBW EIRP, OUT OF BAND	.004	10		
AWGN, E_b/N_o = 8.5 dB	.988	10	4.6×10^{-3}	4.7×10^{-3}
FINITE CW RFI, 50 dBW EIRP, IN BAND	.004	10		
INFINITE NOISE OR CW, 100 dBW EIRP, OUT OF BAND	.008	10		

TABLE 2.13-1

COMPARISON OF ERROR RATES OBTAINED THROUGH HARDWARE AND SOFTWARE SIMULATORS, UNDER RFI CONDITION (HARDWARE SIMULATOR WITHOUT INTERLEAVER)

The results generated by the synchronization algorithm for a random gaussian channel were very close to the ones found by Linkabit. In addition, the structure of metric growth and monitoring have been discussed in detail with Linkabit. The conclusion is that the synchronization routine of the software simulator performs as the routine in the hardware simulator.

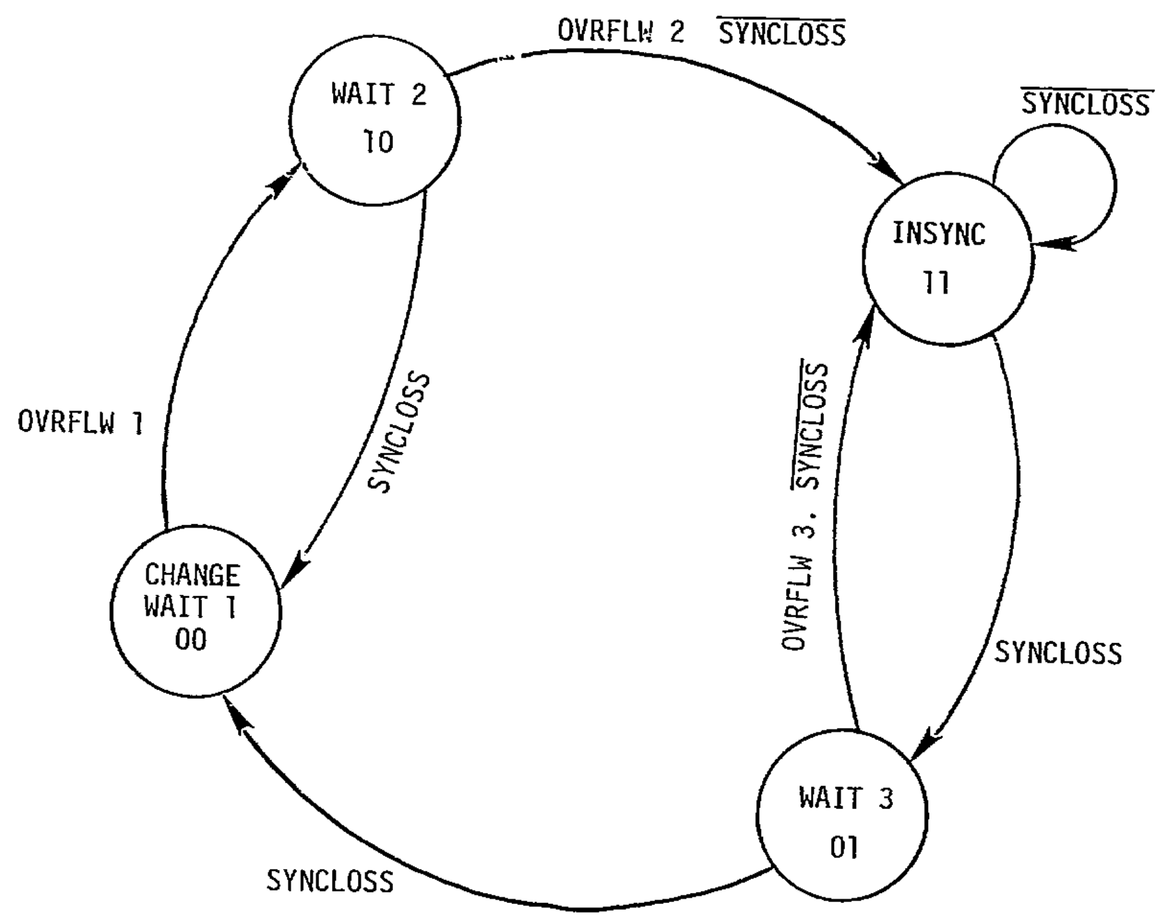
2.13.3 Synchronization Behavior in Gaussian Environment

Tests were run to determine the average time required for the decoder to generate the SYNCLOSS signal (see Figure 2.13-1) when the deinterleaver has lost synchronization. For an AWGN channel with an Eb/No = 4.4 dB (rate 1/2) the average time to generate SYNCLOSS is 215 channel symbols. One hundred signals were generated of which 20 took longer than 240 channel symbols. From this the average time required for the deinterleaver to start the synchronization search can be calculated, and is 544 channel symbols after the loss of synchronization occured. There is a 94% probability that the deinterleaver starts the synchronization search within 885 channel symbols after the start of the loss of synchronization.

The maximum time to generate SYNCLOSS was 324 channel symbols. State 10 has a waiting period of 500 channel symbols. Even though the search strategy may require the generation of SYNCLOSS 29 times before the correct synchronization state is acheived the probability of going from state 10 to state 11 (INSYNC) erroneously, i.e., when the deinterleaver is not synchronized, is negligibly small.

2.13.4 Minimum Metric Growth

The growth of the minimum metric in the Viterbi decoder is the parameter on which the detection of loss of synchronization is based. The average growth of the minimum metric has been measured to be:



WAIT 1 - 3600 CH. SYMBOLS
WAIT 2 - 500 CH. SYMBOLS
WAIT 3 - 240 CH. SYMBOLS

PROB(TIME TO SYNCLOSS IF OUT OF SYNC > 240 S) = .2

FIGURE 2.13-1: DEINTERLEAVER SYNCHRONIZATION SEARCH

- When the symbols into the decoder have a random pattern:

  Average Minimum Metric Growth = $\overline{MMG_R}$

  $$\text{constant} \times \frac{1}{2} \times \sum_{i=1}^{4} i\,(q_{4-i} + q_{3+i})$$

- When the symbols into the decoder have the appropriate coded pattern, i.e., the deinterleaver is synchronized:

  Average Minimum Metric Growth = $\overline{MMG_S}$ =

  $$2 \times \sum_{i=1}^{4} i\, q_{4-i}$$

with

- q_j = the j'th soft quantization level, with
  j = o the worst quantization level and
  j = 7 the best quantization level

- constant between .8 and .95 emperically determined.

The formula for $\overline{MMG_S}$ is valid only if the decoder error rate is better than 10^{-2} errors/bit.

The hardware simulator monitors the minimum metric growth. If this exceeds .4444 per decoder output bit for an extended period of time (e.g., 50 - 300 output bit), the decoder generates a SYNCLOSS signal.

2.13.5 Space Telescope Environment

The quantization levels for the RFI environment expected for the Space Telescope were calculated with STI's software package COSAM. A total of nine RFI environments were included (Table 2.13-2).

The predicted error rate for the composite channel as shown for a memoryless channel, i.e., either RFI pulse durations of less than one symbol or an

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TABLE 2.13-2

SPACE TELESCOPE RFI ENVIRONMENT

	CHANNEL DESCRIPTION	R_o	HARD DECISION SYMBOL ERROR PROB.	DUTY CYCLE
1	AWGN E_b/N_o = 5.4 dB	.59515	.06264	.7
2	FINITE NOISE RFI, EIRP = 8 dBW	.59385	.06294	.1
3	FINITE NOISE RFI, EIRP = 18 dBW	.58230	.06567	.13
4	FINITE NOISE RFI, EIRP = 28 dBW	.48437	.09133	.03
5	FINITE CW RFI, IN BAND, EIRP = 38 dBW	.00943	.42222	.0057
6	FINITE CW RFI, OUT-BAND, EIRP = 38 dBW	.14923	.24217	.0143
7	INFINITE CW RFI, IN BAND, EIRP = 100 dBW	$.191\ 10^{-5}$	.50	.0051
8	INFINITE NOISE RFI, OUT-BAND, EIRP = 100 dBW	$.191\ 10^{-5}$	.50	.0129
9	INFINITE CW RFI, IN BAND, EIRP = 100 dBW	$.191\ 10^{-5}$	.50	.00057
10	INFINITE NOISE RFI, OUT-BAND, EIRP = 100 dBW	$.191\ 10^{-5}$	.50	.00143
	COMPOSITE CHANNEL	.47527	.07729	

PREDICTED ERROR RATE: 10^{-5} ERRORS/BIT ideal deinterleaver, is 10^{-5} errors/bit. The simulation on the hardware simulator resulted in an error rate of 1.1×10^{-5} errors/bit. The pulse durations were all one symbol and the interleaver was switched in. No loss of synchronization was observed.

Because of the limited accuracy of the hardware simulator for the transition probability matrix, a straight forward simulation of the channel as shown in Table 2.13-2 is not possible if pulse duration of 10 symbols are specified. By combining a number of environments, an approximate equivalent composite channel was obtained with 4 RFI environments with pulse durations of 10 symbols. Again with the interleaver in, there was no loss of synchronization after 360 Mbits. The error rate was 2.8×10^{-5}.

Some more tests were run with the most severe form of RFI (environment 7) and the interleaver. With a pulse duration of 7 symbols and a duty cycle of .028, no synchronization loss was observed. The error rate was 3×10^{-5} errors/bit. However, with a pulse duration of 10 symbols and a duty cycle of .038, there was an occasional loss of synchronization and the error rate jumped to $7.8\ 10^{-3}$ errors/bit. The loss of synchronization cannot be explained with what is known at present about the average minimum metric growth. Further investigations are directed towards the momentary minimum metric growth and testing the effectiveness of the deinterleaver. It should be noted that the expected duty cycle of this particular RFI is around .00567, which is a factor 5 smaller.

2.13.6 Pulsed RFI and Decoder Without Deinterleaver

Figure 2.13-2 illustrates the environment selection scheme utilized in describing the Viterbi decoded error performance as a function of increasing RFI symbol duration.

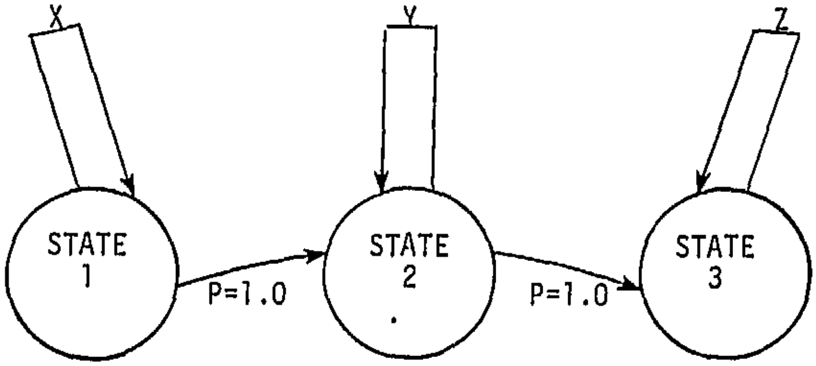


FIGURE 2.13-2: CHANNEL ENVIRONMENT SELECTION FOR NON-INTERLEAVED DECODER PERFORMANCE

STATE 1 & 3: GAUSSIAN ENVIRONMENT DESCRIBED BY A SNR = 4.4dB

STATE 2: CW RFI ENVIRONMENT, EIRP = 100.00, WHERE X, Y, AND Z ARE THE CHANNEL SYMBOL HOLD TIMES WHICH "FORCE" THE ENVIRONMENT FOR THESE RESPECTIVE VALUES.

In this study, the RFI duration was varied from 1 to 300 channel symbols, and the hold time Z was constant at 400 symbols, allowing a reasonable observation window following the RFI to Gaussian environment transition. The hold time X was varied in accordance to the RFI symbol duration so that X + Y + Z = 1000. Simulation runs were performed inside the 300 RFI symbol range in order to determine the mapping of interference pulse width to the number and sequence of incorrectly decoded bits. The output listings complementing the simulation runs include a decoded bit error propagation map, a channel symbol degradation map, and accumulated minimum metric growth monitor, a synchronization loss indicator, and statistics describing synchronization state interarrival times.

The initial results in this non-interleaved channel scenario indicate that the Viterbi decoder returns to the right decoding path very rapidly after entering the State 3, and only occasionally the error burst exceeds the RFI duration with pulse durations below 20 symbols.

The generation of the SYNCLOSS signal due to one RFI pulse requires a pulse of a duration exceeding 100 symbols. This is supported by measurements of SYNCLOSS interarrival times when the RFI environment is selected continuously.

2.13.7 Software Development

The software for the software simulator has been expanded. The output provides the opportunity to measure the error propagation, the growth of the minimum metric and the inter arrival times of the generation of SYNCLOSS. With the present code up to 11, different environment can be specified. The code is documented with "structured" comments which allows first time users to apply and modify the code with a minimum of instruction.

2.13.8 Task 13A - Ku-Band Pulsed RFI Performance

This paragraph covers Task 13A work.

2.13.8.1 Task Description. The objectives of this study are to model Ku-Band pulsed RFI seen by TDRS on the return link and use the model, together with CLASS to evaluate the RFI impact on Shuttle Channel 3 coded performance. The specific subtasks consist of:

- Developing a set of RFI pulse statistics that would be typical of the environment that the TDRS return link Ku-band channel will see.
- Inputting the RFI statistics to the COSAM modules of CLASS to generate soft decision statistics that are representative of Shuttle Channel 3 operation (50 Mbps, rate 1/2 coded) within the geographical RFI zone; these statistics should reflect the non-linear nature of the TDRS transponder.
- Inputting the soft decision statistics to the Viterbi decoder hardware simulator, resident at NASA/GSFC, to ascertain decoder output BER performance; these results should reflect the absence of interleaving/deinterleaving

2.13.8.2 Ku-Band RFI Model. The Ku-Band RFI of interest is pulsed in nature and the number of emitters are relatively small (e.g., 10 to 15). Furthermore, these emitters are randomly distributed over the geographic region of interest.

The primary goal in modeling Ku-Band RFI is EIRP vs. duty cycle as a function of user satellite location. This RFI statistical representation is precisely the one that has been used in S-band RFI evaluations. Accordingly, once this Ku-Band model is developed, the existing COSAM modules of CLASS that have been previously applied to S-band evaluations can be straightforwardly applied to the Ku-band case. Note, however, the following fundamental difference between the S-band and Ku-band scenarios:

- For S-band, the RFI seen by TDRS is assumed to be fixed, but attenuated by the degree of TDRS antenna offpointing from the boundary of the defined RFI zone; typically S-band evaluations were made for 0°, 1.5° and 4.0° offpointing angles.

- For Ku-Band, the RFI seen by TDRS is a function of the TDRS antenna pointing <u>plus</u> the underlying parameters of the pulsed RFI emitters (sweep rate, pulse duration, antenna pattern, elevation locations, angle emitter); accordingly, Ku-Band RFI performance evaluation requires the determination of an updated RFI statistical characterization (duty cycle vs. EIRP) for each user satellite location.

The general methodology Ku-band RFI model generation and the interaction with CLASS are illustrated in Figure 2.14-1.

2.13.8.3 <u>Application of RFI Model and CLASS to Ultimate Performance Evaluation</u>. As discussed above, for each user location, a statistical characterization of duty cycle vs. RFI EIRP is to be developed. As in previous S-band evaluations, this characterization, together with a specification of other salient signal and channel parameters serve as inputs to the COSAM modules of CLASS. Specific channel and signal parameters of interest include:

- data rate
- coded/uncoded
- channel bandwidth
- TDRS transponder nonlinearity (AM/AM and AM/PM)
- uplink and downlink carrier to noise ratios

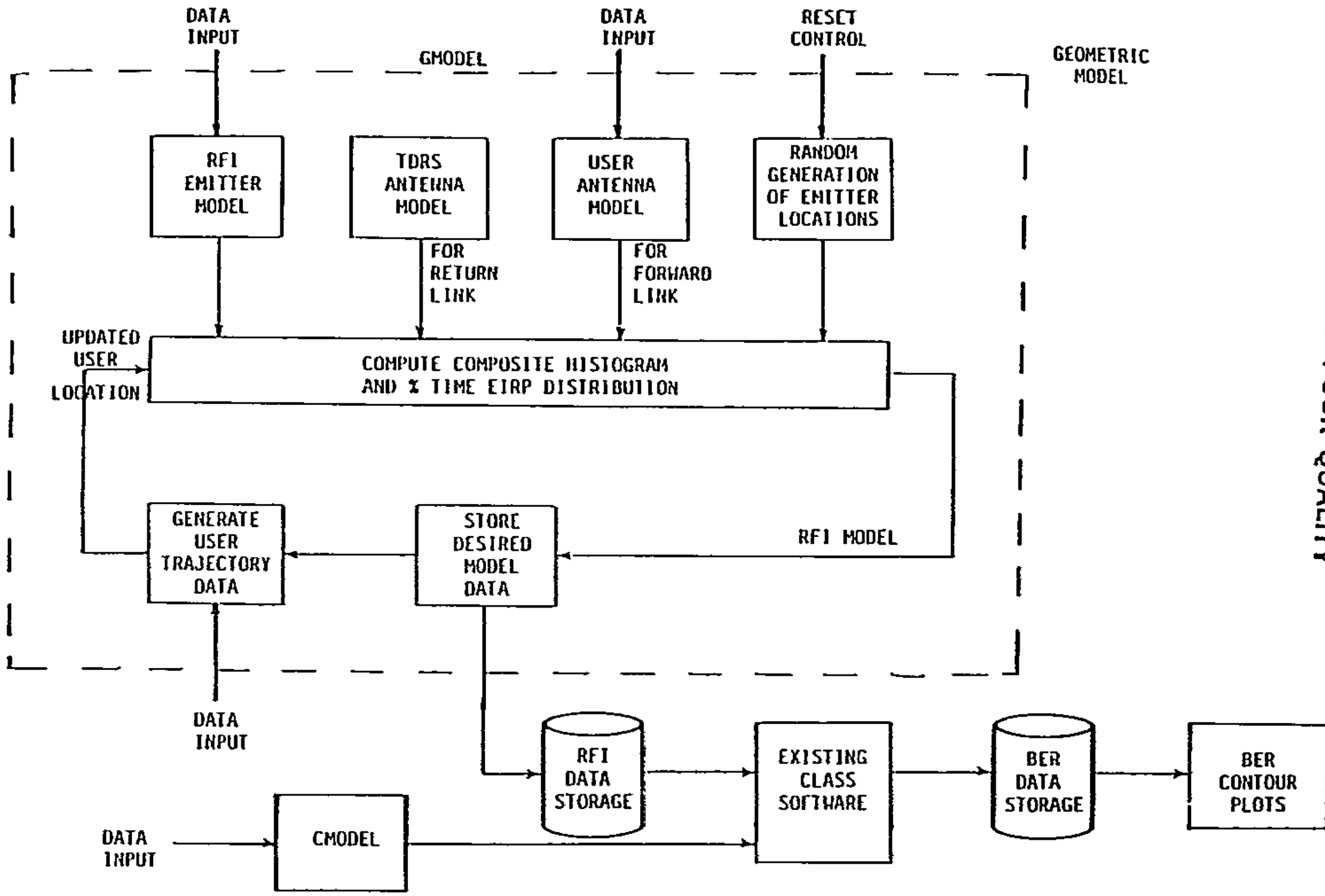


FIGURE 2.14-1
OVERVIEW OF RFI CHANNEL MODEL

The above set of input parameters allows CLASS to evaluate hard decision BER values for uncoded operation and soft decision probability distributions (SDD) for coded operation (rates 1/2 and 1/3). Of particular interest here, is the rate 1/2 coded scenario. The CLASS output consists of a conditional SDD, given each form of RFI present, and the composite SDD, wherein the conditional SDD's are weighted by their respective duty cycles and summed. The conditional SDD may be directly transformed into decoder output BER if the channel yielding the SDD is memoryless in nature; this, for example, is the case when interleaving/deinterleaving is employed. Under Ku-Band conditions, however, interleaving is not used. Accordingly, for sufficiently high data rates, such as in Shuttle Channel 3 operation, the channel is not memoryless and an alternate approach must be used to evaluate performance. This is described in the following.

2.13.8.4 Viterbi Decoder Hardware Simulator. The Viterbi decoder hardware simulator, which is resident at NASA/GSFC and is being used in Task 13 may also be applied to the Shuttle Channel 3 scenario. Specifically, the hardware simulator is designed to take as inputs a large number of distinct conditional SDD's and the set of transition probabilities from one SDD state to another. Based on the described capability, it is then possible to use CLASS to generate the conditional SDD's for Shuttle Channel 3 operation; the set of transition probabilities may also be readily evaluated from knowledge of duty cycles and RFI pulse-to-information symbol duration ratios. Since the hardware simulator allows for real time decoder hardware simulations with and without interleaving/deinterleaving, Shuttle Channel 3 performance can be ascertained. The significance of the hardware simulator capability should be emphasized since there is no known analytical method for estimating Viterbi decoder performance when the input statistics reflect channel memory. In concluding this discussion it should be noted that with the aid of hardware simulators it will be possible to determine what RFI levels are required to cause decoder loss of lock. This coupled with CLASS and the Ku-band modeling capability described earlier will allow for a determination of the geographic zones over which channel 3 performance degredation may be overly severe.

2.13.8.5 Task Status. To this date the Ku-Band modeling software has been developed and we are now in a position to generate the RFI statistics for Shuttle Channel 3 operation. During the month of November, these statistics will be generated and inputted to CLASS to yield the associated SDD's. During November, the Viterbi decoder hardware simulator will be exercised to yield the ultimate performance results of interest.

2.14 TASK 14 - DEEP SPACE SUPPORT

This task is concerned with assessing the feasibility of providing Deep Space mission support with TDAS. Figure 2.14-1 presents a block diagram of the major task elements and the interface with other TDAS study tasks.

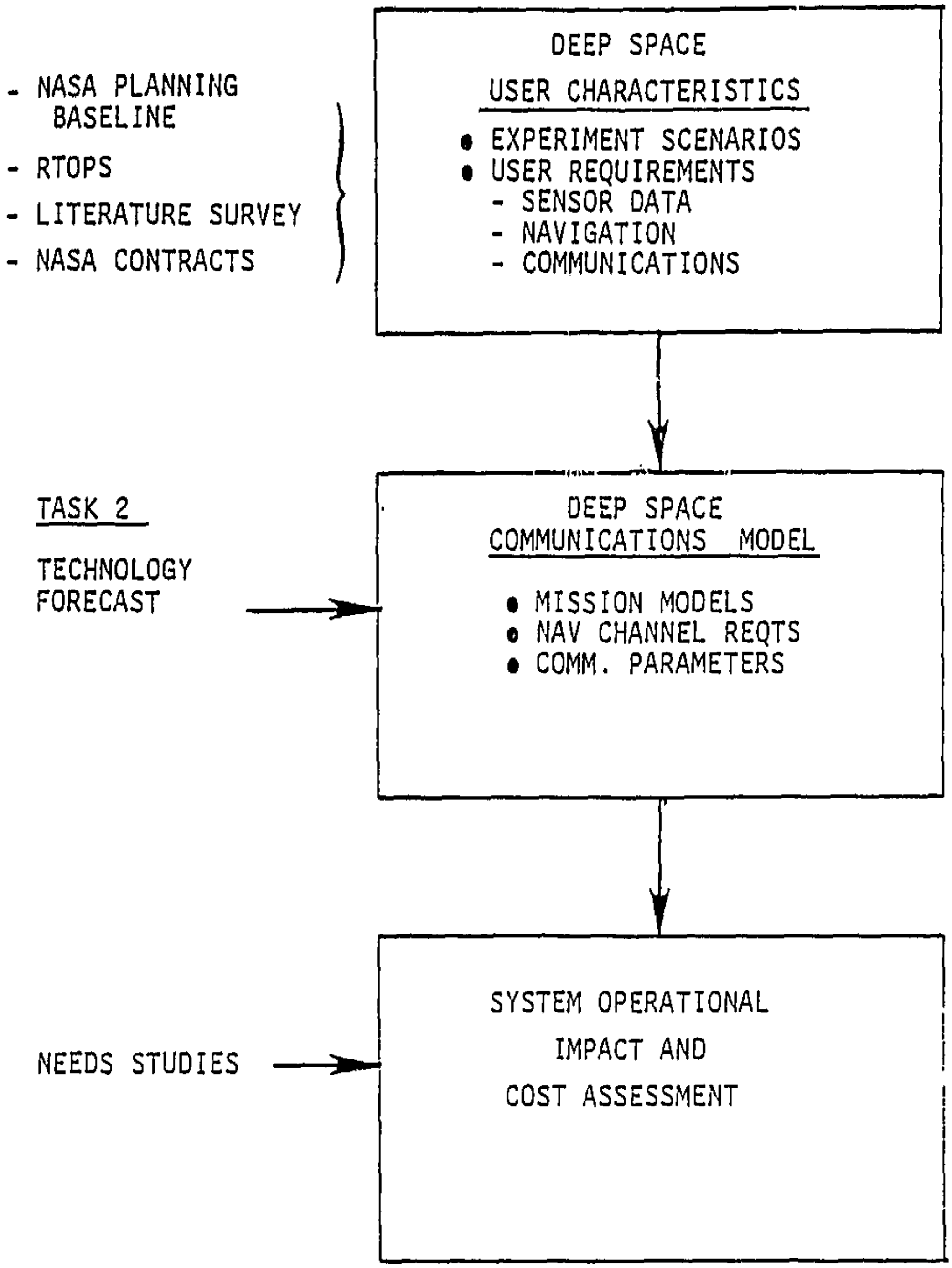
Experiment Scenarios and user requirements will be developed for use in defining a deep space communications model. Preliminary mission models will be defined and estimates of the impact of the Deep Space mission support on system operations and cost will be made. A technical assessment will also be made of the system-wide impact of Deep Space support to facilitate a decision on whether to include this capability in TDAS architecture and operations planning.

The initial effort concerned gathering background data necessary for defining scenarios of experiments pertaining to deep space activity in the 1990's. Literature was reviewed, and contacts with NASA/JPL personnel have been made to discuss potential mission planning.

This effort is currently on hold pending internal efforts underway at JPL to update their planning to the point where a meaningful scenario of mission models can be defined to pursue this task.

FIGURE 2.14-2

TASK 14 ELEMENTS



SECTION 3

NEW TECHNOLOGY

No "New Technology" reporting requirements were identified during this reporting period.

SECTION 4

PROGRAM FOR NEXT REPORTING INTERVAL

All tasks are referenced here for completeness, although not all of them will be active.

4.1 TASK 1 - USER COMMUNICATION CHARACTERISTICS

Completed. No work schaduled.

4.2 TASK 2 - SPACECRAFT DATA SYSTEM ARCHITECTURE

This subsection outlines the task 2 efforts to be pursued within the next quarter.

4.2.1 Technology Forecast

The technology forecast of remaining components in the sensor data handling and communication areas will be completed. The items that remain to be addressed are really subsystems comprised of components and some components are used in various subsystems. It is for these components that the technology will be forecasted and inferences for the subsystems will be drawn therefrom.

4.2.2 User Spacecraft System Architectures

All the necessary user spacecraft architectures will be developed.

4.2.3 User Spacecraft Costing

The cost of the user spacecraft for which architectures are developed, will be estimated.

C-2

4.2.4 System Performance Assessment Simulation

The user spacecraft portion of the simulation will be completed. This pertains primarily to the Communication Traffic Simulator and Spacecraft Motion Simulator noted previously in Figure 2.2-13.

4.3 TASK 3 - TDAS COMMUNICATION MISSION MODEL

A few loose ends remain to complete the Task 3 draft final report. These include link budget revisions and addition of elements of a military mission model to the TDAS communication mission model. The draft final report will be completed by the third week of the next reporting quarter.

4.4 TASK 4 - USER GROUND DATA SYSTEM ARCHITECTURE

This task continues through July 1982. During the next quarterly reporting period, work will include developing a general outline of the user ground data system; generating requirements for the user ground system, and performing preliminary modeling of requirements. Subcontractor support will be provided by SPACECOM for this task, for user ground system cost estimates and related matters.

4.5 TASK 5 - TDAS SYSTEM ARCHITECTURE AND SUBTASK 5A - TDAS RETRIEVAL

4.5.1 Task 5

This task is scheduled to start in November, and continue to the end of the contract. Support will be provided by subcontractors as follows:

- FSEC - Space segment satellite design for the 1st three options from Task 3.

- SPACECOM - Space segment satellite design for the 4th option from Task 3.

A detailed work plan with schedules will be developed at a kick off meeting between STI and subcontractor personnel in mid-November.

4.5.2 Task 5A - TDAS Retrieval

Work on this task will commence in late November and continue for 6 months. During the reporting quarter data will be collected on the capabilities of STS elements designed for retrieval/repair of geostationary satellites. In addition, tradeoff options will be defined for examining the overall replacement vs retrieval/repair issue.

4.6 TASK 6 - USER COMMUNICATION TECHNOLOGY ASSESSMENT

This task is scheduled to start in April 1982. No activity is expected during the reporting period.

4.7 TASK 7 - TDAS COMMUNICATIONS TECHNOLOGY ASSESSMENT

This task is scheduled to start in April 1982. No work is expected during the reporting period.

4.8 TASK 8 - OPERATIONAL ASPECTS

This task is scheduled to start in February 1982. No activity is expected during the reporting period.

4.9 TASK 9 - EXECUTIVE SUMMARY REPORT

This task is scheduled to start in February 1983. No work is expected during the reporting period.

4.10 TASK 10 - FREQUENCY PLAN AND RADIO FREQUENCY INTERFERENCE MODEL DEVELOPMENT AND SUBTASK 10A - FREQUENCY MANAGEMENT

4.10.1 Frequency Plan and RFI Model Development

During the next reporting period, effort will be completed on the four elements of Task 10 and will be reported in detail in the next quarterly report.

4.10.2 Frequency Management

The review of the WARC-79 final acts will be continued in more detail and a review of the 1982 Radio Regulations undertaken when published. Results of Task 10 will be utilized to lead to a Frequency Management position for TDAS.

Coordination/liaison with NASA on the TDAS frequency management issues will continue.

4.11 TASK 11 - THREAT MODEL DEVELOPMENT/SECURITY ANALYSIS

4.11.1 Threat Model Development

During the coming reporting period, additional analysis will be done on the results of the Satellite Control Satellite (SCS) study in order to provide the assessment basis for TDAS. These analysis may include:

- Effect of frequency alternatives
- Update of approved threats
- Alternative geometries
- Alternative antennas

The basic system configurations and signal structures developed in other tasks will be used in applying the results directly to TDAS.

4.11.2 Security Analysis

Work on this task will be initiated in the coming quarter. The objective will be to stipulate operating conditions under which secure operation of TDAS will be achievable. The first job will be to define secure performance as it applies to TDAS. For each system configuration and signal format under consideration, effort will be made to determine allowable ranges of pertinent system parameters such as:

- Data rate
- EIRP
- Receive G/T
- Permissible excess path loss
- Gemetric constraints
- Signal processing requirements

4.12 TASK 12 - UPGRADING THE SAMSO COST MODEL

This task is scheduled for completion by December 1981. During the coming reporting period the plan for completing this task is based on the following steps:

- Complete comparison of SAMSO and GSFC satellite cost models and comparison with actual cost data as available from RAG for satellites in several weight classes:

- SMS-1	(low weight, spin stabilized)
- Landsat-1,2,3	(medium weight, 3 axis stabilized)
- HEAO-1	(higher weight, 3 axis stabilized)
- SMM	(MMS configuration, 3 axis stabilized)

- Determine requirements for modifying appropriate costs estimating relationships (CERs) in SAMSO model.

- Complete the Task 12 Draft Final Report.

4.13 TASK 13 - VITERBI DECODER/SIMULATOR STUDY

During the next quarter the following areas of this task will be pursued:

- Test the synchronization algorithm for a variety of synchronization parameters.

- Modelling the synchronization detection process on the basis of parameters which can be measured in a simple manner.
- Issue the interim report.
- Further evaluate the decoder performance without deinterleaver for pulsed RFI environments.

4.14 TASK 14 - DEEP SPACE SUPPORT

By late December or early January a preliminary package is anticipated from JPL which deal with a 20 year mission model for deep space, spacecraft requirements for this mission set and TDAS requirements to support these users.

Upon receipt, activities will resume with a review of this material and efforts will be made to define a preliminary communication mission model.

SECTION 5

CONCLUSIONS

At the end of each task conclusions will be developed for inclusion in following quarterly technical progress report. There are no conclusions for this report since all active tasks remained active through the end of the reporting period, with the exception of Task 1. The Task 1 conclusions are documented in a separate draft final report.

SECTION 6

RECOMMENDATIONS

At the end of each task recommendations will be developed for inclusion in the following quarterly technical progress report. There are no recommendations for this report since all active tasks remained active through the end of the reporting period, with the exception of Task 1, which was completed during the reporting period. The Task 1 results are documented in a separate draft final report.

APPENDIX A

SUBCONTRACTORS REPORTS:
FAIRCHILD SPACE & ELECTRONICS COMPANY

926-QR-001

TRACKING AND DATA ACQUISITION SATELLITE SYSTEM (TDAS)

QUARTERLY PROGRESS REPORT

Prepared for

STANFORD TELECOMMUNICATIONS, INC.
1195 Bordeaux Drive
Sunnyvale, CA 94086

Prepared by

FAIRCHILD SPACE & ELECTRONICS COMPANY
20301 Century Boulevard
Germantown, MD 20874

Under Subcontract No.

STI-5-26546-1

Prime: NAS5-26546

October 1981

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This document represents the first Quarterly Progress Report for Subcontract STI-5-26546-1, under Prime Contract No. NAS5-26546. The period of performance covered by this report is from July 1, 1981 through September 30, 1981.

The effort covered by this document is for Study Tasks 1 and 2. Task 1, "User Community Characteristics", was completed satisfactorily and was concerned with developing experiment scenarios for generating alternate mission models for the TDAS during the 1990 time period. The material generated during this effort was incorporated into the STI report to NASA for Task 1 and was submitted to NASA during the first quarterly presentation to the NASA/GSFC Technical Officer.

Task 2, "Spacecraft Data System Architecture" is currently in progress and is concerned with defining the TDAS user spacecraft data system architectures. This data will then be used for estimating spacecraft costs which will be used in later tasks addressing cost trade-offs among other TDAS system elements. It is estimated at this juncture that Task 2 will be completed on schedule and within the allowable funding.

1.0 INTRODUCTION

This quarterly report documents the progress made by Fairchild Space & Electronics Company (FSEC) in the performance of TDAS Study Tasks 1 and 2. It provides an overview of the progress made and the nature of the scientific and technical results obtained. Additionally, it proves the necessary information for the management of the contract.

1.1 REPORTING PERIOD

The period covered by this report is July 1, 1981 through September 30, 1981.

1.2 SCOPE OF WORK

This document covers FSEC's activity as a subcontractor to STI on NASA Contract No. NAS5-26546.

This contract represents a two-year pre-Phase A concept definition study for the proposed Tracking and Data Acquisition Satellite System (TDAS), designated as the follow-on to the Tracking and Relay Satellite System (TDRSS) currently in development. TDRSS operation will extend to approximately 1994. Consequently, TDAS study will cover a 10-year planning period starting in the early 1990's.

Classification of carriers for experiments flown during the TDAS time frame are grouped into the following three classes:

- Free Flyers
- Platforms
- Space Stations

In general, platforms provide the capability to group experiments together on an unmanned carrier, while the space stations provide a manned facility capable of carrying one or more experiments. The space shuttle is expected to be in operation beyond the year 2000, with five to seven launches occurring during this study period.

TDAS will be required to support low earth orbit (LEO) missions regarding communications, navigation, and TT&C. Additional requirements may be generated by user mission activities in higher (eg, synchronous) orbits, and by the need to support inter-orbital transfers of materials and men for in-orbit maintenance and repair or for retrieval of platforms and experiments. The scope of work also covers examination of the possibility of using TDAS resources in support of deep space experiments.

A critical area in the development of TDAS is the requirement to handle earth resource observations. High data rates (eg, Multispectral Linear Array-MLA) are generated for certain types of observations. Sensors such as the MLA may require downlink data rates in excess of all other TDAS users combined. Other activities, such as the Power Utilization Program (PUP) may also have large data requirements. This study therefore includes identification of requirements and cost trade-off analysis for on-board data processing either in the user satellite or TDAS, to reduce bandwidth/power requirements.

The study also defines the terrestrial communications requirements and technology to be developed. Overall optimization of space/ground arthitecture is considered to define viable architectural choices in meeting user needs for transmission of experiment data to user ground terminals, user commands for experiment operation, and related needs for vehicle TT&C, navigation, pointing and timing accuracy.

In the initial development of mission profiles, military requirements for TDAS support are excluded. However, these will be considered as the study progresses. It is assumed that shuttle flights carrying military missions will need TDAS support.

1.3 FSEC'S INVOLVEMENT

During this reporting period, FSEC was involved in the following activities:

1. Task 1: "User Community Characteristics"
2. First Quarterly Presentation to NASA.
3. Task 2: "User Spacecraft Systems"

1.4 SUMMARY OF WORK PERFORMED

1.4.1 Task 1

This task was satisfactorily completed. The material generated during this phase was submitted to STI for integration into the Task 1 Report.

1.4.2 First Quarterly Presentation

Material was generated on user spacecraft systems for the first quarterly presentation to NASA. This material was also presented by FSEC to a select audience of personnel from both civilian and military agencies and private industry.

1.4.3 Task 2

This task is in process.

1.5 TASK REPORTS

1.5.1 Introduction

Progress accomplished during Tasks 1 and 2 is detailed in subsequent paragraphs.

1.5.2 Task 1: User Community Characteristics

This task is concerned with developing two scenarios of experiments that will form the basis for generating alternative sets of mission models for the Tracking and Data Acquisition System (TDAS) in the 1990's time frame. To accomplish this, a Baseline of Plans within the aerospace community will be developed for the 1990's time frame. Naviation and communication requirements will be identified and a set of alternative forecast options to be developed.

Missions and experiments identified and assigned to FSEC using NASA literature sources for considerations as candidates during the TDAS time period, were evaluated in depth. The characteristics for these missions/experiments were obtained from a literature search, NASA reports, and interviews with mission planners and NASA program managers. The STI standard format form was used to document these characteristics. As an illustrative example of data obtained, refer to the Solar Soft X-ray Telescope facility discussed in Table 1.1 The characteristics not defined by NASA (marked TBD) were estimated and, those of user community members, which were the responsibility of FSEC, were collected in the manner shown and formatted for integration into the final report.

1.5.3 First Quarterly Presentation to NASA

Attached is the material on user spacecraft systems prepared for the first quarterly presentation to NASA. FSEC presented this material in coordination with other parts of the presentation.

1.5.4 Task 2. Spacecraft Data System Architecture

1.5.4.1 Introduction

This task is concerned with defining data system architectures for potential TDAS user spacecraft and estimating the corresponding spacecraft costs for use in later tasks that address cost trade-offs among other TDAS elements. Figure 1.1 presents a block diagram of the major task elements and the interface with other TDAS study tasks.

The spacecraft data system architectures will be defined based upon mission constraints and related technology forecasts for the 1990s. Spacecraft costs for each mission will be estimated using cost model information developed in Task 12. In addition, part of an overall System Performance Assessment Simulation (SPAS) program dealing with user spacecraft data system performance will be developed.

TABLE 1.1

EXAMPLE OF TASK 1 DATA COLLECTION

STATUS: PLANNED

B-31: Solar Soft X-Ray Telescope Facility (82)

OBJECTIVE: The Solar Soft X-ray Telescope Facility has as its purpose fundamental observations of the outer solar atmosphere. Specific objectives are to determine the mass flow and energy deposition in the corona, to understand the formation and evolution of coronal features and their relationship to changes in the photosphere and chromosphere, to identify the sites and processes that produce solar flares, and to assess the relationship between the large scale structures of the corona and solar magnetic fields and the interplanetary solar wind and magnetic sector structure.

DESCRIPTION: The Solar Soft X-ray Telescope Facility is being studied as a candidate Shuttle/Spacelab payload to be launched after 1987 (approx.); a new start after FY 84 is assumed. Instruments for the telescope facility are to be selected by the Announcement of Opportunity process. The telescope consists of a set of confocal mirrors of the Wolter type I configuration for observations from 0.175 to 10 nm. A smaller telescope, coaxial and confocal with the larger telescope, will provide imaging at short wavelengths. A spatial resolution of 0.5 arc sec is desired. An evolutionary program of Shuttle flights is planned for the Facility using increasingly sophisticated focal plane instrumentation. The Facility will be mounted on pallets in the Shuttle bay and pointed to the Sun by the ESA Instrument Pointing System (IPS). Data from the observations will either be recorded on film or telemetered to Earth via the Shuttle/Spacelab Command and Data Management System (CDMS) and the Tracking and Data Acquisition System (TDAS).

ORBIT PARAMETER:

Altitude: 430 Km
Inclination: 56°
Carrier: Shuttle/Spacelab
Launch Date: After 1987
Flight Duration: 7 - 30 days
Flight Activity Profile: See Note (1)

NOTE (1): As informed by C. Stouffer GSFC, an evolutionary plan of Shuttle flights is planned for the facility at the rate of 2 flights per year for a period of 10 years. Thus, the lifetime will extend into TDAS era. A total of 20 flights over a period of 1990 to 2000 will take place. The experimental setup may not go in the same shuttle orbiter each time.

SPACECRAFT REQUIREMENTS:

Field of View: Full disc coverage of the sun
Power: 240 W (Average consumption)
360 W (Peak consumption)
Size: 6 m long x 1.2 m dia
Mass: 1,300 (total mass at operational location)

Table 1.1,
B-31: (Continued)

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DATA CHARACTERISTICS:

Experiment Sensor Data Rate: 60 kbps (min), 14 Mbps (max)(1)
Experiment Control Data Rate: 1 kbps(2)
Mission TT&C Data Rate: 2 kbps(3)
On-Board Data Storage: Yes
Daily Data Volume: 1.406×10^6 bits/day(4)
On-Board Processing: Yes(5)
Processed D/L Data Rate: TBD

NOTES (1): The experiment provides imaging data. Two imagers are considered for the experiment; these are (1) photon analyzing imager and (2) energy integrating imager. Their respective data rates (max. buffered data rates) are 60 kbps and 15 Mbps (Transmission rate 4 Mbps.

(2): This value is estimated based upon similar experiments.

(3): This value is estimated based upon similar missions.

(4): Based upon the asumption that 100 imagers are collected per day with imager.

(5): Following on-board processing functions are required
  a. Energy Integrating Imager requires on-board data compression
  b. Both imagers require on-board data buffering and on-board TV display generation.

NAVIGATION REQUIREMENTS:

Position Accuracy: TBD
Pointing Accuracy: 0.005 mrad
Stability: 0.001 mrad
Time Requirement: TBD
Techniques: GPS Eventually

TDAS CONTACT TIME PROFILE:

Forward Link - Contacts/Day: TBD
Forward Link - Hours/Contact: TBD
Return Link - Contacts/Day: Continuous
Return Link - Hours/Contact: Continuous

DATA DISTRIBUTION/PROCESSING FLOW:

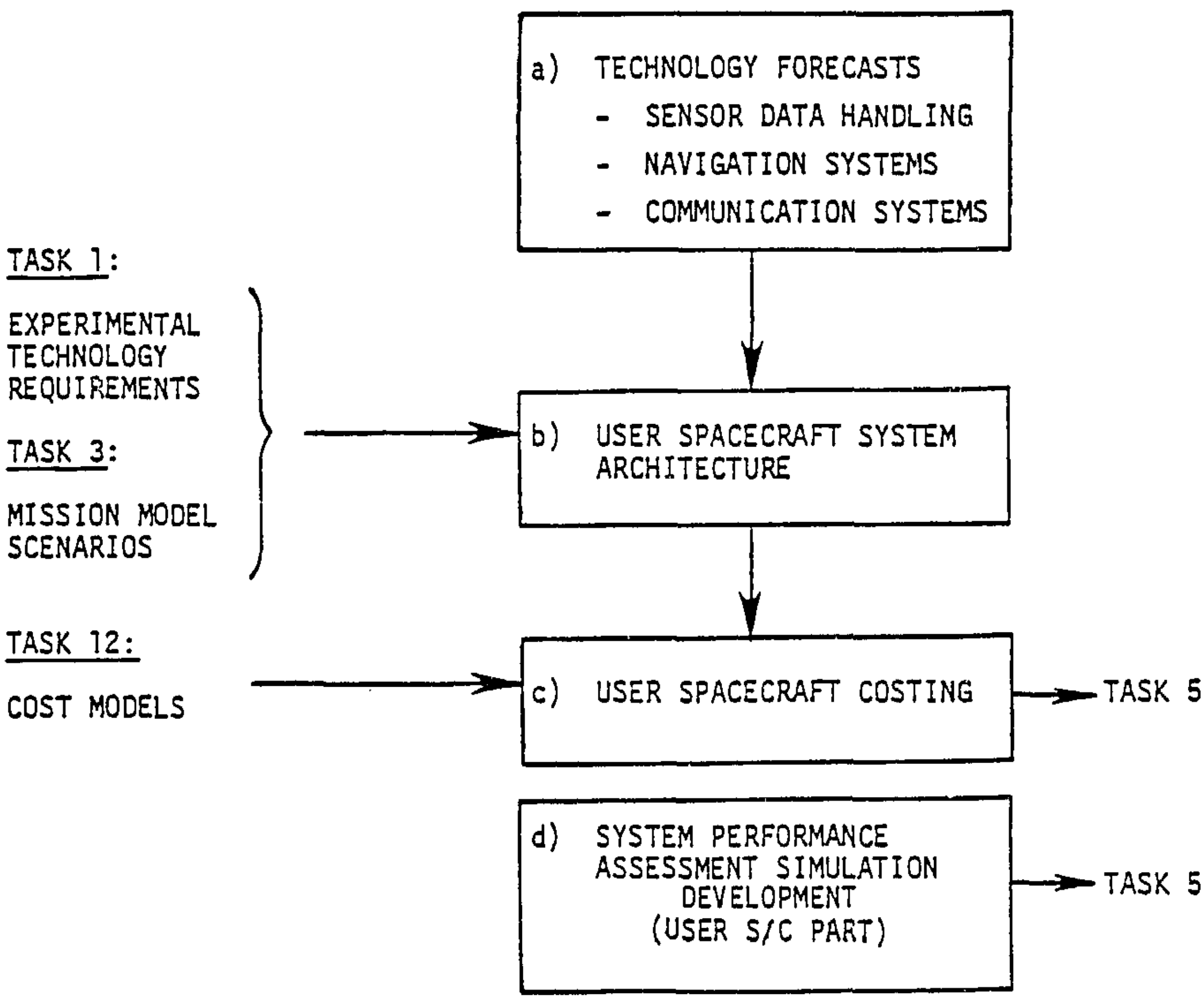
TBD

NASA CONTACTS:

Charles G. Stouffer

FIGURE 1.1

TASK 2 ELEMENTS AND INTERFACES



1.5.4.2 Technology Forecast

FSEC is generating a forecast of technology applicable to the 1990's in the areas of user spacecraft sensor data handling and communications systems. In performing this activity, consideration is also being given to other factors which could affect the user spacecraft interface with TDAS, including the elements of NASA's End-to-end Data Systems (NEEDS) concept.

1.5.4.3 Method of Approach

The detailed method of approach followed for sensor data handling systems will use the information sources identified by the following:

- TDAS Baseline
- Navigation Techniques
- NASA Space Systems Technology Model
- NASA Program Planning and Position Papers
- NEEDS Program Approaches.

Requirements and constaints as defined by the TDAS baseline will be used to carry out the following forecasting activity:

1. Investigate data handling approaches including:
   - Packetizing Data
   - Data Compression
   - OB Data Processing
   - Remote S/C Processing by Users

2. Project OB computer thruput and mass storage capabilities to reduce transmission data rate.

3. Investigate future data communication methods
   - Evaluate Future Data Communication Methods
   - New Coding Schemes for Higher Coding Gain
   - Secure and Spread Spectrum Communication

4. Technology Survey Thru Industry Contact of
   - OB Processors
   - Memories
   - Tape Recorders
   - Sensors

For communication systems, the method of approach consists of forecasting baseband and RF equipment technologies. These components are as follows:

1. Baseband Components
   - Modems
   - Codecs
   - Multiplexers/Demultiplexers
   - Synchronizers
   - Sequence Generators
   - Code lock loops
   - Interleavers/Deinterleavers
   - Source and Channel Encoders

2. RF Components
   - Antennas
   - HPAs
   - LNAs
   - RF Filters
   - Diplexers/Circulators
   - Frequency Converters
   - Phase-locked loops
   - Frequency Synthesizers

For components in the sensor data handling and communications systems areas, the forecast activity projects improvement in the pertinent parameter(s) over the time frame of interest. The fundamental technology, advancement responsible for projected improvements is identified and the relevance of the forecasted parameter(s) to the overall TDAS System is emphasized. Where applicable, all frequency regions of interest include the S, ku, ka, mmw and laser bands. Existing literature (both NASA and other), assessment of new technology on component development and interviews with component manufacturers provide inputs for the forecast activity. As an example, results of HPA technology forecasts are provided in Figures 1.5.1 through 1.5.3.

1.6 PROBLEMS ENCOUNTERED/SOLUTIONS OBTAINED

J. Schwartz, the NASA program manager for the TDAS effort identified J. Kauffmann, NASA/GSFC as the point of contact for accomplishing the technology forecasting effort. J. Kauffmann was unavailable until early October. Various efforts to reach J. Kauffmann to date have not been too fruitful; however, a continued effort will be made to set up an appointment with him.

1.7 EXPENDITURE STATUS

During the reporting period, the number of hours productively spent on Tasks 1 and 2 are given as follows:

Task 1: 152 hours
Task 2: 84 hours

1.8 SCHEDULE

Task 1 has been completed on schedule.
Task 2 is proceeding on schedule.

1.9 ACTIVITY FOR THE NEXT REPORTING PERIOD

Task 2 performance will continue.

TWT RF Power

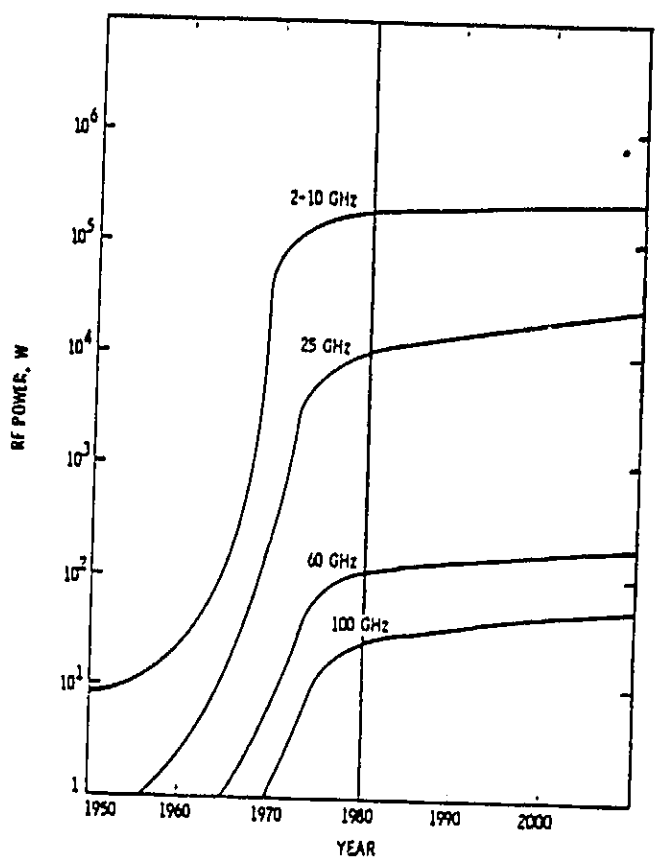


Figure 1.5.1

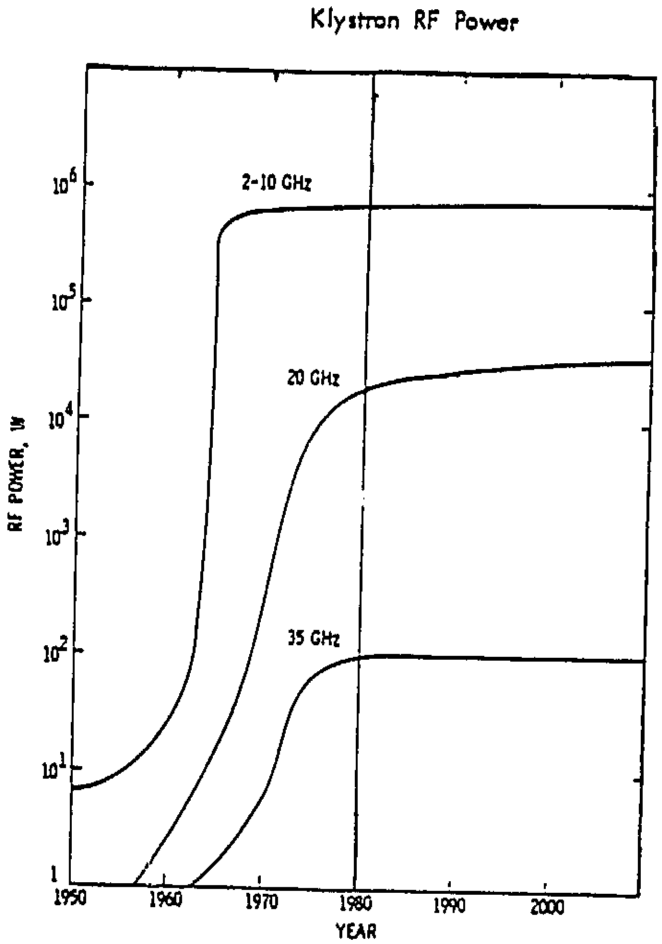

Klystron RF Power
2-10 GHz
20 GHz
35 GHz
RF POWER, W
10^6
10^5
10^4
10^3
10^2
10^1
1
1950
1960
1970
1980
1990
2000
YEAR

Figure 1.5.2

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Solid-State Power-Frequency Characteristics

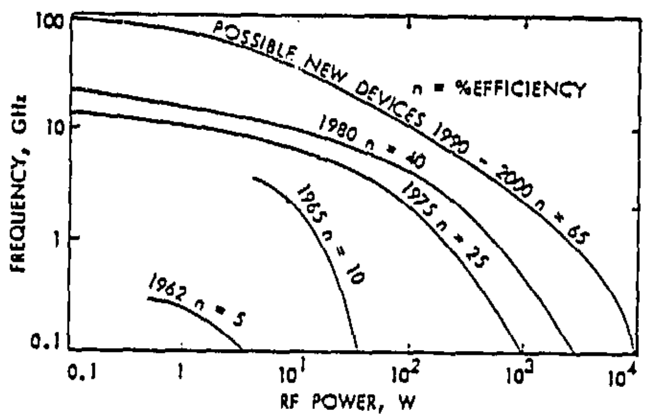


Figure 1.5.3

ATTACHMENT A

USER SPACECRAFT SYSTEMS

SUBTASKS

A. TECHNOLOGY FORECASTS

- SENSOR DATA SYSTEMS
- COMMUNICATIONS
- NAVIGATION (COVERED EARLIER)

B. USER S/C ARCHITECTURE

C. USER S/C COSTING

OBJECTIVES

OBJ:1. FORECAST FOLLOWING S/C TECHNOLOGY FACTORS WHICH AFFECT USER S/C — TDAS INTERFACE

- SENSOR DATA SYSTEMS
- COMMUNICATIONS SYSTEMS

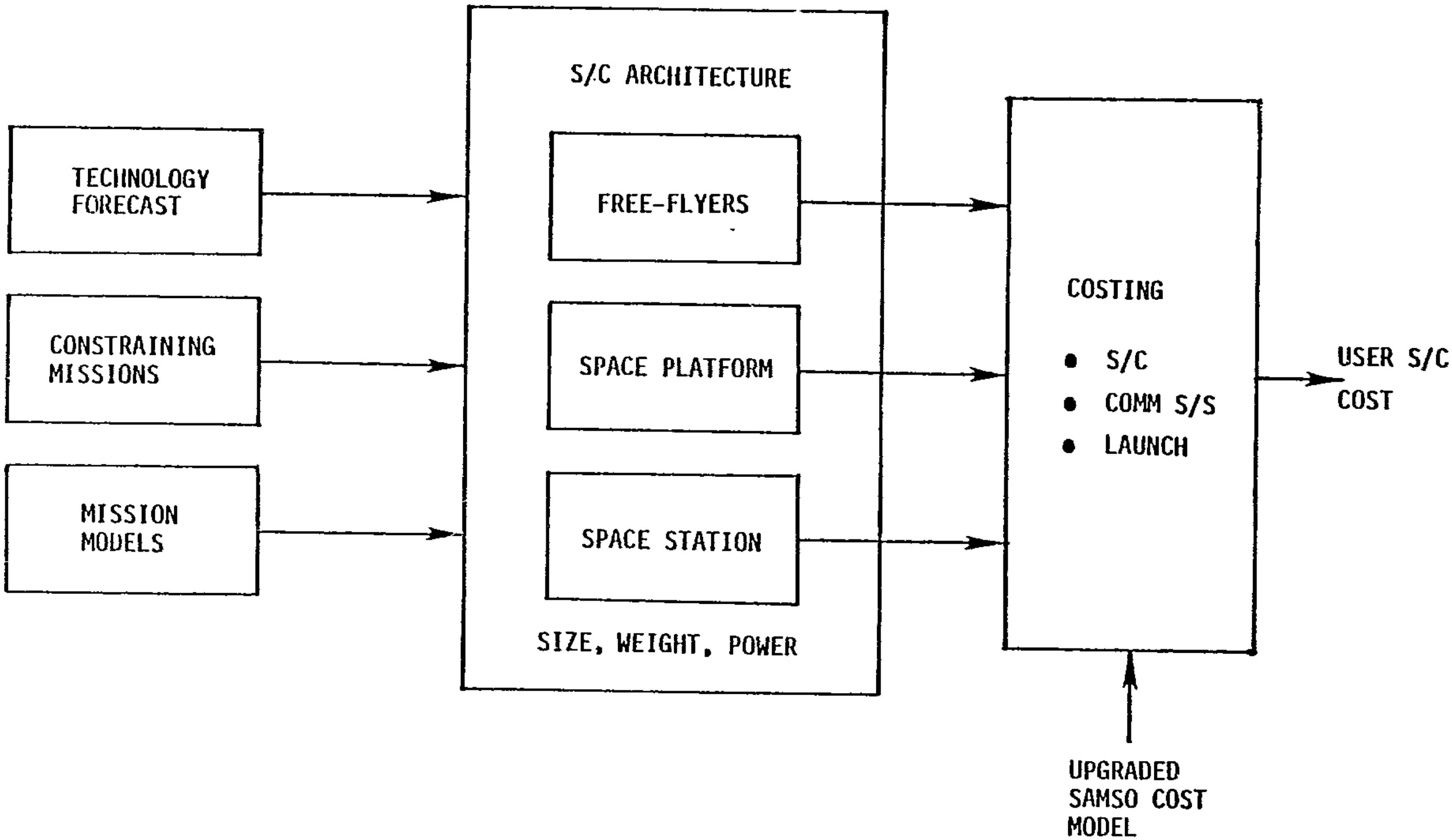
2. DEVELOP CONCEPTS FOR S/C ARCHITECTURES FOR FOLLOWING MISSION MODELS

- FREE FLYERS
- SPACE PLATFORM
- SPACE STATION

ESTIMATE SIZE, WT AND POWER FOR EACH S/C ARCHITECTURE

3. ESTIMATE USER S/C COST

USER S/C SYSTEMS ACTIVITY FLOW



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DETAILED PLAN OF ATTACK

TECH FORECASTING:
(SENSOR DATA SYSTEMS)

INFORMATION SOURCES

- TDAS BASELINE
- NAVIGATION TECHNIQUES
- NASA SPACE SYSTEMS TECHNOLOGY MODEL
- NASA PROGRAM PLANNING AND POSITION PAPERS
- NEEDS PROGRAM APPROACHES

REQMTS AND CONSTRAINTS

- TDAS BASELINE REQMTS
- NAVIGATION ACCURACIES

ACTIVITY

1. INVESTIGATE DATA HANDLING APPROACHES INCLUDING
   - PACKETIZING DATA
   - DATA COMPRESSION
   - OB DATA PROCESSING
   - REMOTE S/C PROCESSING BY USERS

2. PROJECT OB COMPUTER THRUPUT AND MASS STORAGE CAPABILITIES TO REDUCE TRANSMISSION DATA RATE

3. INVESTIGATE FUTURE DATA COMMUNICATION METHODS
   - EVALUATE FUTURE DATA COMMUNICATION METHODS
   - NEW CODING SCHEMES FOR HIGHER CODING GAIN
   - SECURE AND SPREAD SPECTRUM COMMUNICATION

4. TECHNOLOGY SURVEY THRU INDUSTRY CONTACT OF
   - OB PROCESSORS
   - MEMORIES
   - TAPE RECORDERS
   - SENSORS

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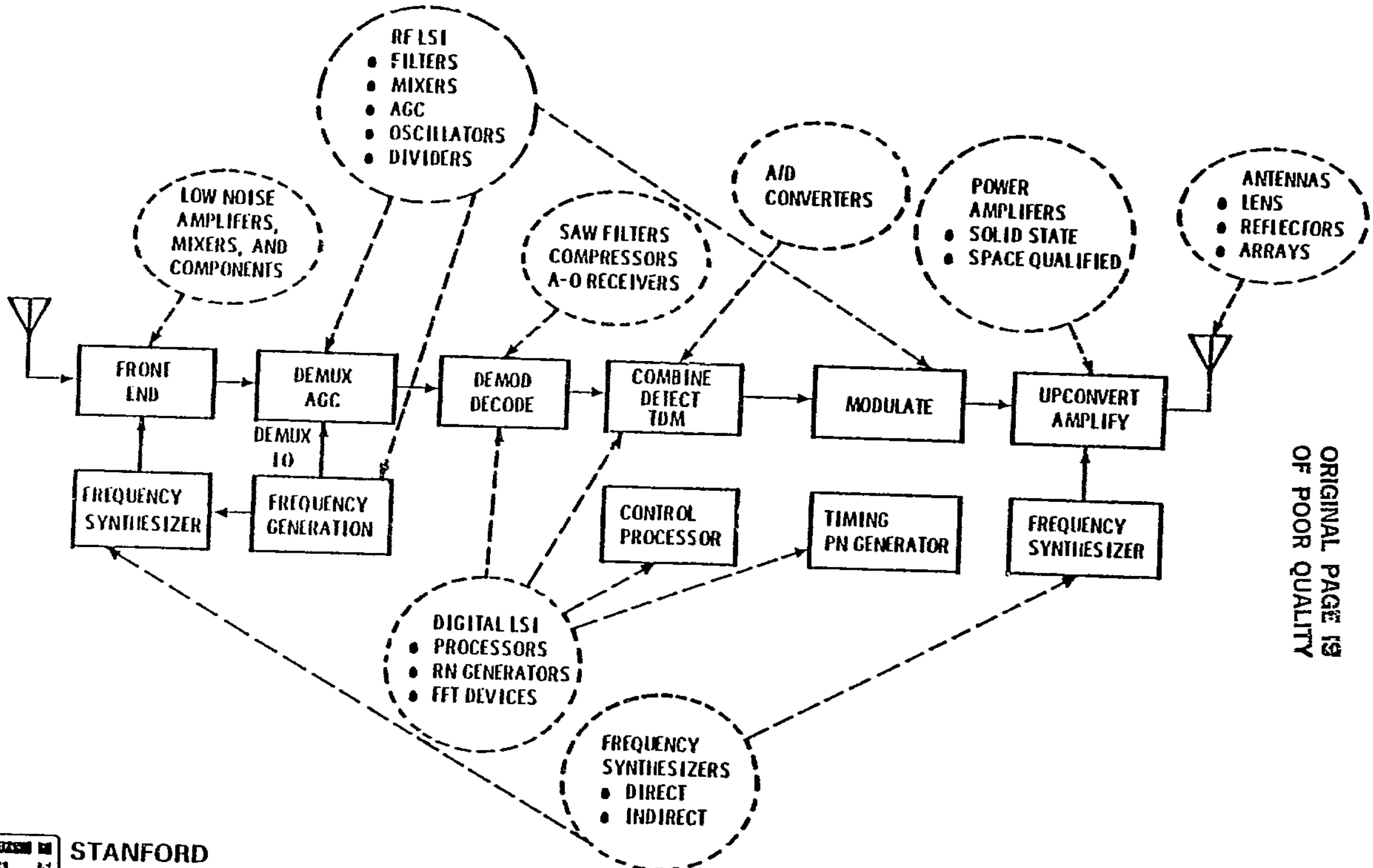
DETAILED PLAN OF ATTACK (CONT'D)

TECH FORECASTING: COMMUNICATIONS: IDENTIFY COMM: TECHNOLOGIES WHICH CAN BE ASSUMED FOR GENERATING ALTERNATIVE TDAS ARCHITECTURES

COMMUNICATIONS EQUIPMENT TECHNOLOGIES

BASEBAND TECHNOLOGY	RF TECHNOLOGY
MODEMS	ANTENNAS
CODECS	HPA'S
MULTIPLEXERS/DEMULTIPLEXERS	LNA'S
SYNCHRONIZERS	RF FILTERS
SEQUENCE GENERATORS	DIPLEXERS/CIRCULATORS
CODE-LOCK LOOPS	FREQ: CONVERTERS
INTERLEAVERS/DEINTERLEAVERS	PHASE LOCKED LOOPS
SOURCE & CHANNEL ENCODERS	FREQUENCY SYNTHESIZERS

TECHNOLOGY IMPACT ON S/C
DATA COMM SYSTEM



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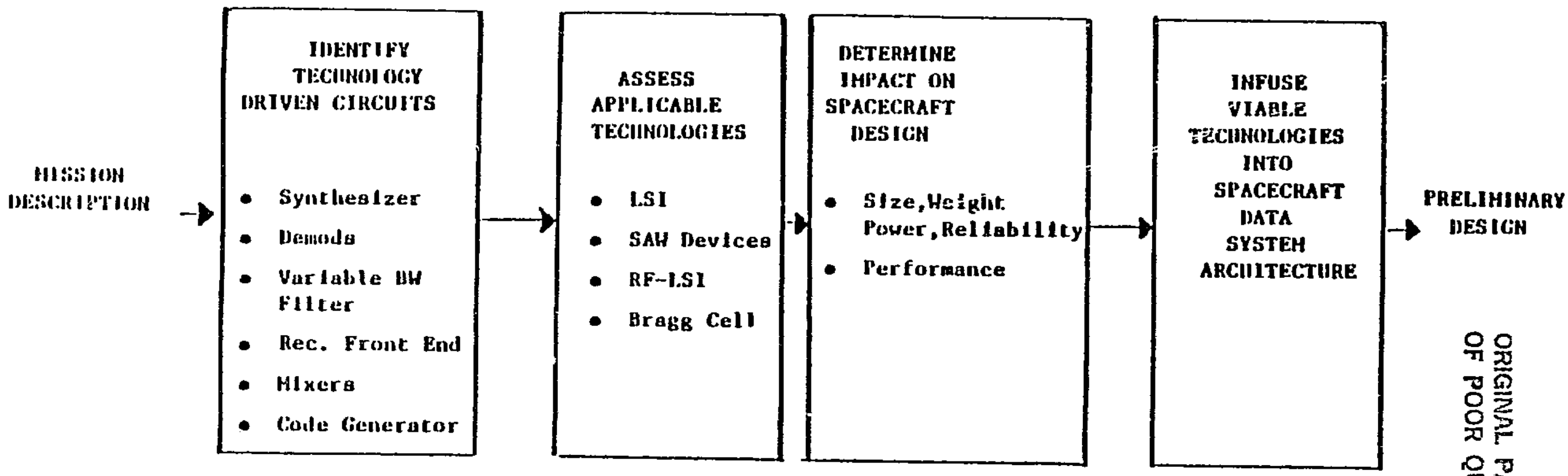
EXAMPLE

COMMUNICATION FORECASTING



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PRELIMINARY RESULTS (TECH: FORECASTING)
DATA CODING/DECODING SCHEMES

TECHNIQUE	PRESENT CODING GAIN	PROJECTED CODING GAIN	CAUSE
CONVOLUTIONAL CODING R = 1/2, K = 7/VITERBI SOFT DECISION DECODING	5 dB (@BER: 10^{-5})	8 DB	VLSI TECHNOLOGY WILL ALLOW THE USE OF LARGER CONSTRAINT LENGTHS (≈14) WITH COMPACT EQUIPMENT.
LOW REDUNDANCY BLOCK CODES/MAX:LIKELIHOOD SOFT DECISION DECODING	CODE DEPENDENT	≈ 2DB GREATER	MICROPROCESSORS & VLSI CHIPS WILL ALLOW COMPACT IMPLE-MENTATION OF SOFT DECISION DECODERS
BLOCK CODING/ERROR CORRECTION AND FILLING ERASURES	CODE DEPENDENT	≈ 2DB GREATER	DIGITAL SIGNAL PROCESSING HARDWARE WILL ALLOW HANDLING BOTH ERRORS AND ERASURES

DIGITAL SIGNAL PROCESSING TECHNOLOGY

PROCESSOR COMPONENT	PRESENT CAP	PROJECTED CAP	TECHNOLOGY
BUFFER	1 GBPS	10 GBPS	VLSI
A/D CONVERTER	20 MBPS	50-100 MBPS	VHSIC
DIGITAL FILTERS	DESIGNED AS INDIVIDUAL UNITS	DESIGNED AS BANKS OF FILTERS	VLSI
FFT PROCESSOR	10 NSEC/OPN	1 NSEC/OPN	VHSIC

VIDEO DATA COMPRESSION

TECHNIQUE*	PRESENT BIT RATE (MBPS)	PROJECTED (COMPRESSED) BIT RATE (MBPS)	CAUSE
UNCOMPRESSED	90	90	WITH PRESENT TECHNOLOGY PROJECTED DATA COMPRESSION IS POSSIBLE WITH BULKY EQUIPMENT. IN TDAS ERA SIGNAL PROCESSING COMPONENTS & VLSI TECHNOLOGY THEN AVAILABLE WILL ALLOW THE TECHNIQUES TO BE COMPACTLY IMPLEMENTED FOR S/C USE.
DPCM		30	
FRAME-TO-FRAME CORRELATION		15	
RUN LENGTH CODING		22.5	
TYPICAL TRANSFORM TECHNIQUE		22.5	

* ONLY THOSE TECHNIQUES WHICH YIELD "GOOD" PICTURE QUALITY AFTER COMPRESSION ARE LISTED.

RECEIVER FRONT ENDS (60 GHZ)

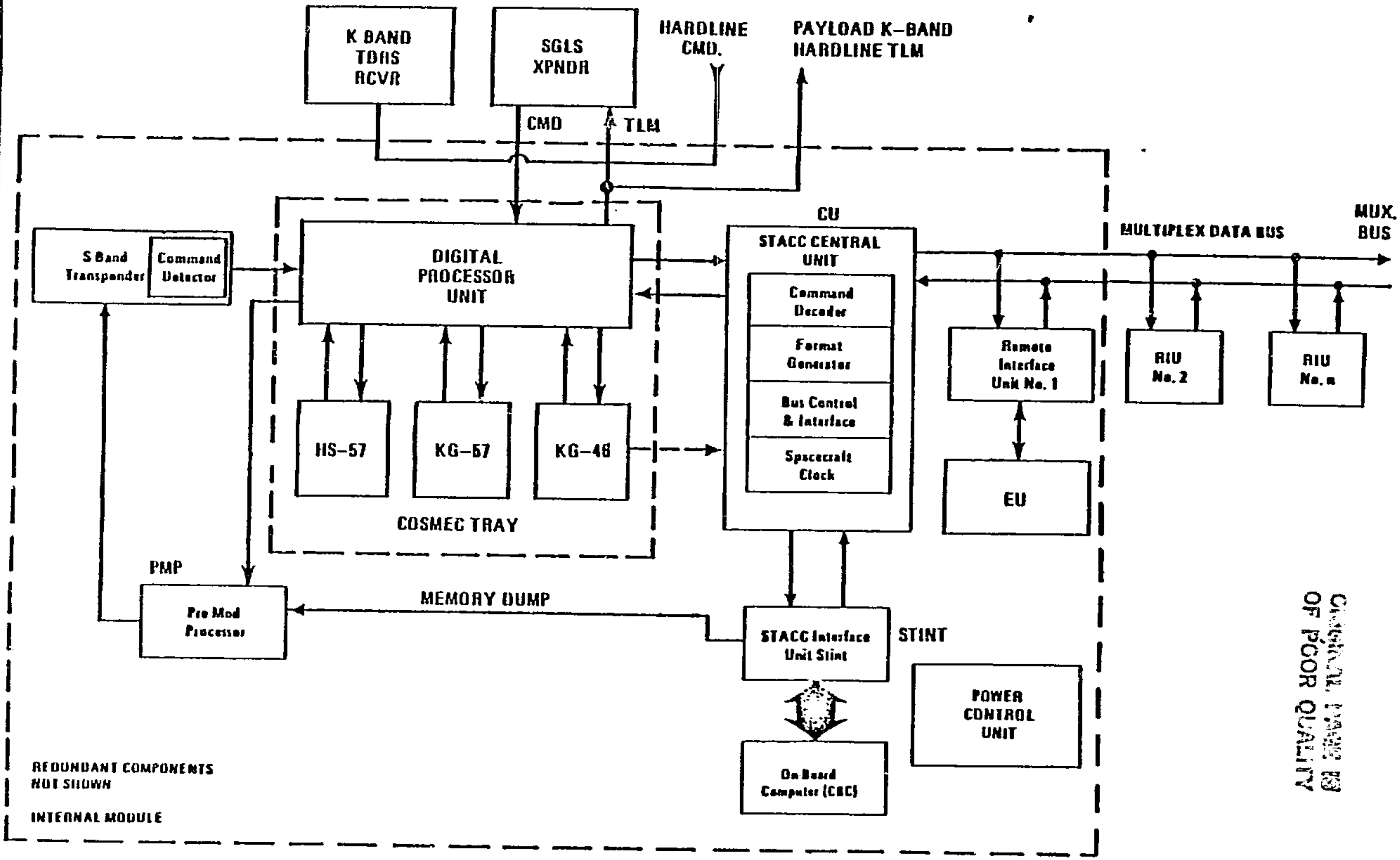
PRESENT		PROJECTED	
TECHNOLOGY	TEMP:°K	TECHNOLOGY	TEMP:°K
PARAMETRIC AMPLIFIER	300	CRYOGENICALLY COOLED PARA-METRIC AMP:	100
FET AMPLIFIER	2000	SUPER CONDUCTING MIXER/IFA	70
IMAGE ENHANCED MIXER/IF AMP:	1000	SCHOTTKY MIXER/IFA	70

ARCHITECTURES

BASELINE CONSTRAINING MISSIONS

- EVOLVE FOLLOWING GENERIC DESIGNS
  - FREE FLYERS (3-AXIS STABILIZED, SPINNER)
  - LARGE SPACE PLATFORMS
  - SPACE STATIONS
- ESTABLISH WEIGHT, POWER AND SIZE FOR EACH
- RESPECTIVE BASELINES FOR ESTABLISHING SIZE, POWER AND WEIGHT FOR GENERIC DESIGNS
  - MMS, ISEE-C S/C
  - CONCEPTUAL DESIGN STUDIES PERFORMED BY NASA
  - STS/SPACELAB MISSION

MMS ARCHITECTURE



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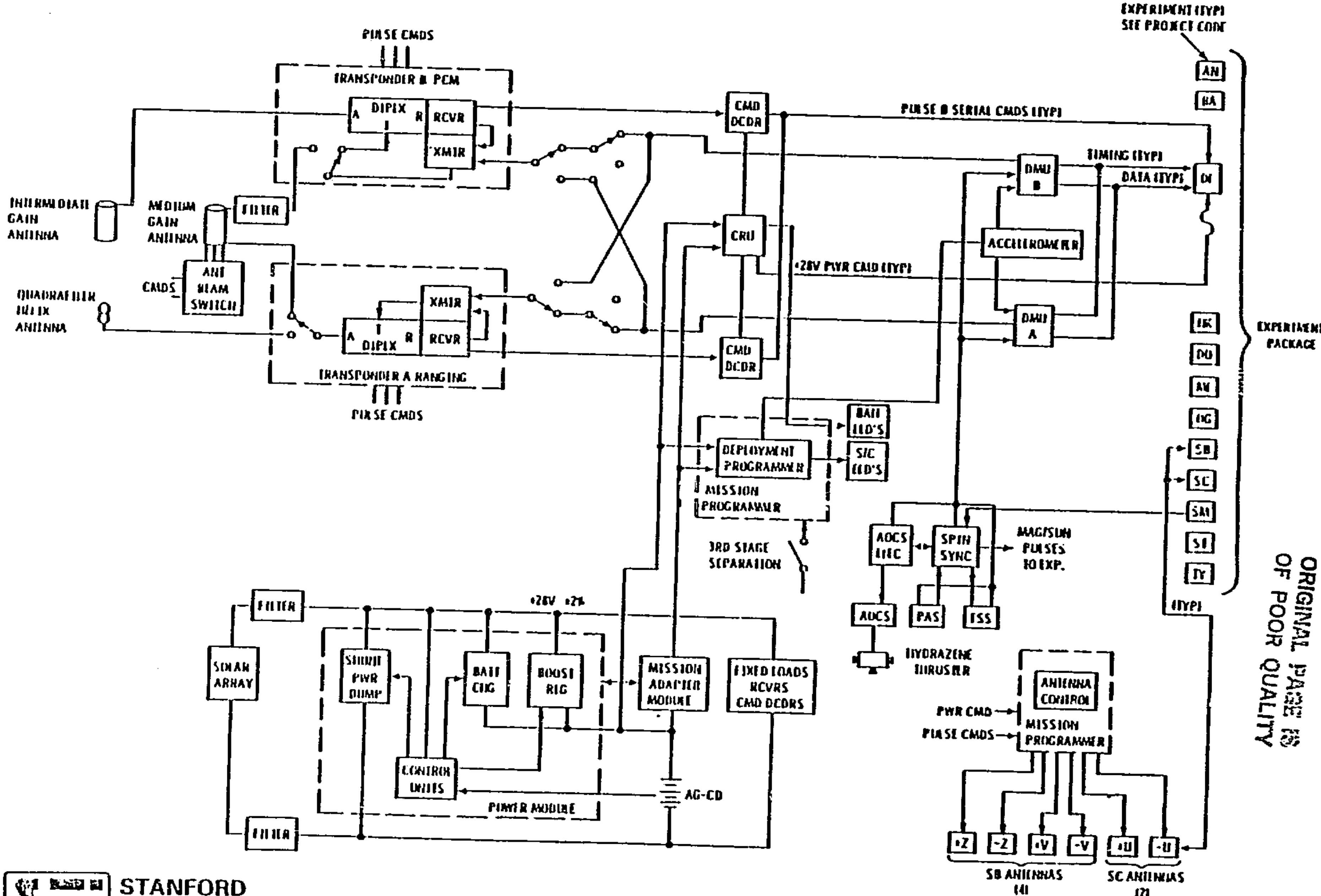
ISEE-C ARCHITECTURE



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USER S/C COSTING

NECESSITY:

1. TRANSMITTING SENSOR DATA FROM USER S/C TO GROUND VIA TDAS IMPACTS NOT ONLY SDH SYSTEM COST BUT ENTIRE USER S/C COST.
2. OPTIMIZATION OF OVERALL SYSTEM COST BY INTERACTIVE PROCESS NECESSITATES USER S/C COSTING.

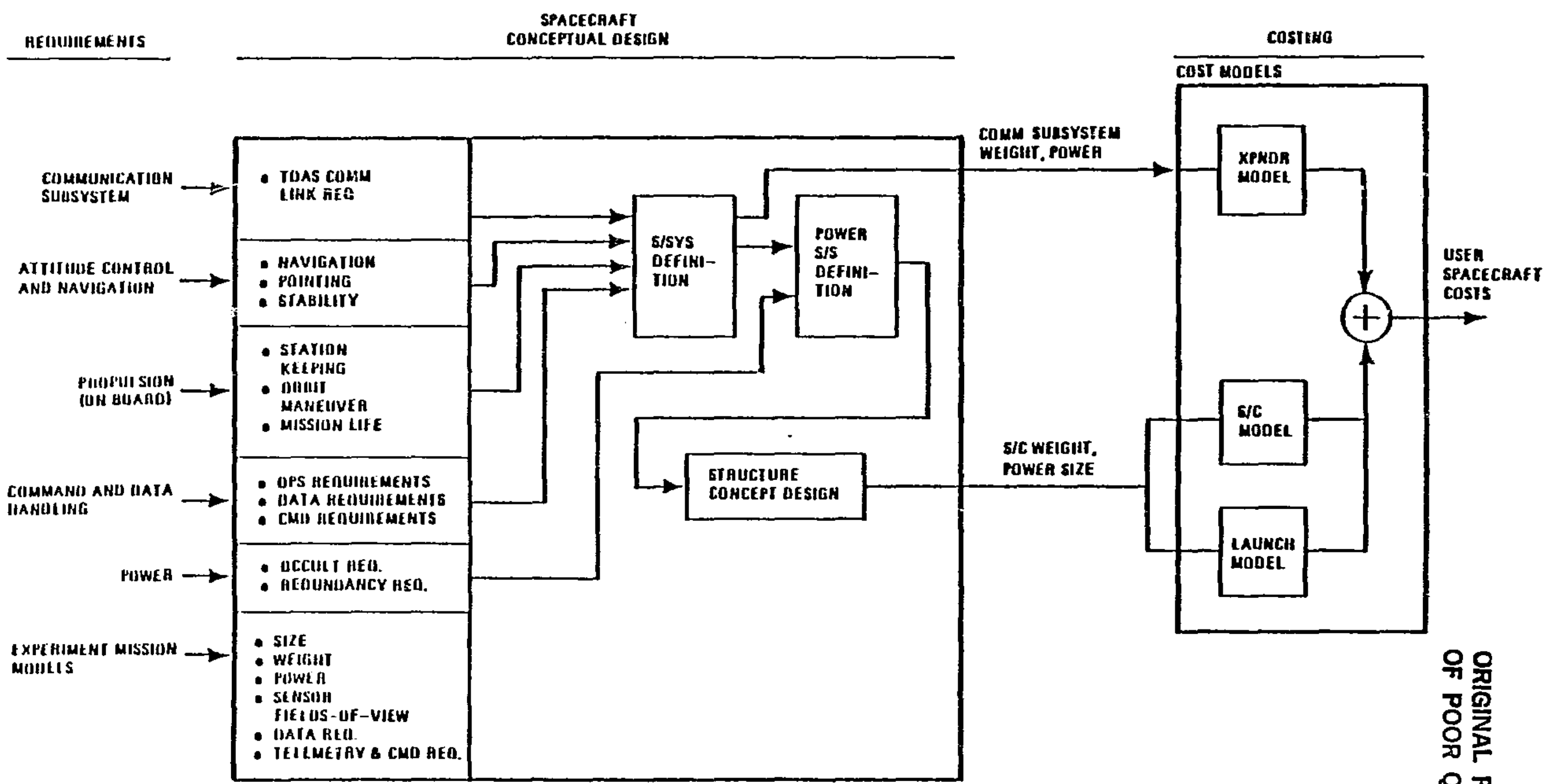
INPUTS:

REQUIREMENTS
S/C CONCEPTUAL DESIGN
S/C SIZE, WEIGHT, POWER
COMMUNICATION SUBSYSTEM WEIGHT POWER
COST MODEL
FORECASTED TECHNOLOGY

OUTPUT:

USERS/C COST

USER S/C COSTING FLOW



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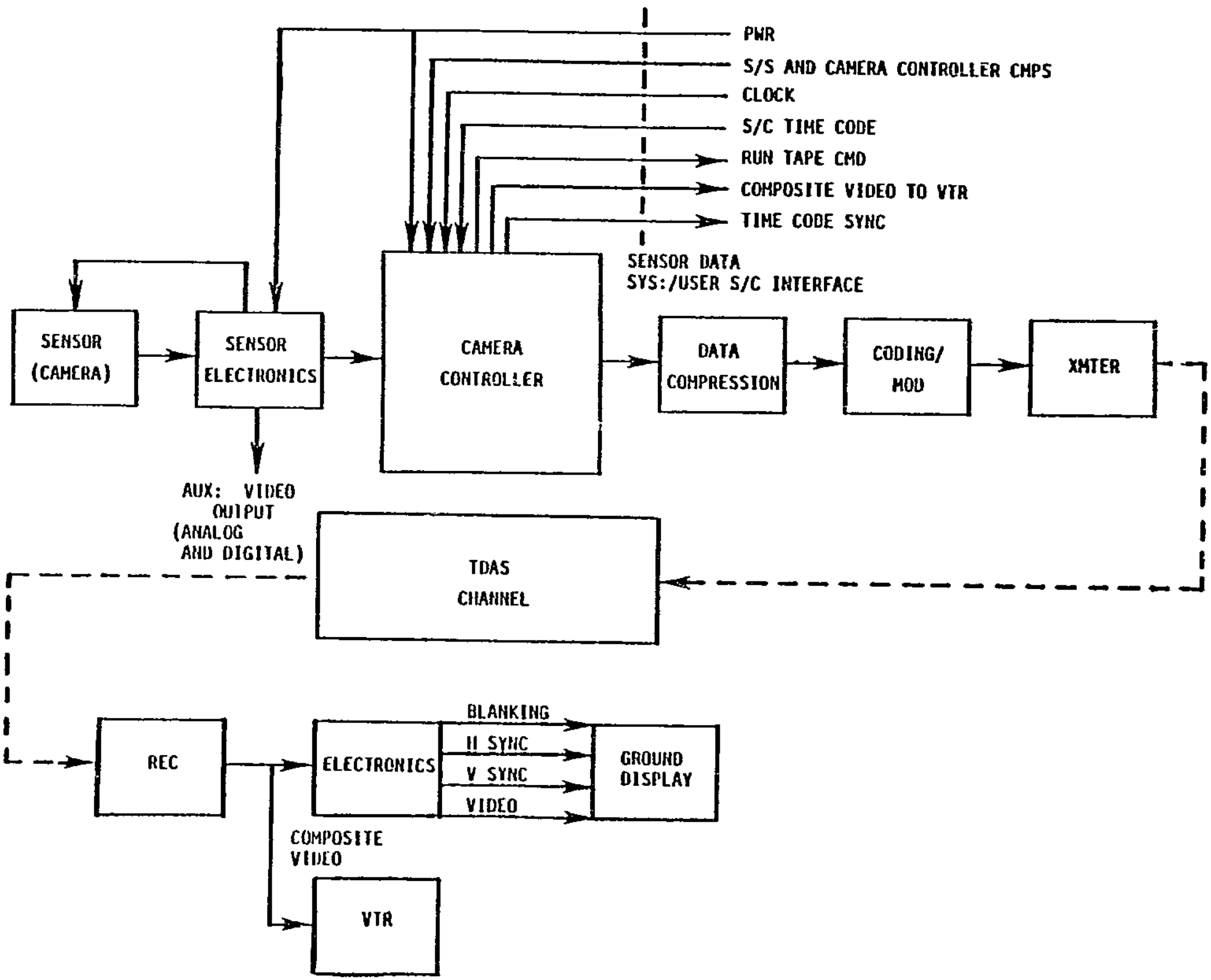
EXAMPLE

OVERALL SENSOR DATA/COMMUNICATION SYSTEM



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